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Inquiry science as a Discourse: New challenges for teachers, students, and the design of curriculum materials

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ABSTRACT

INQUIRY SCIENCE AS A DISCOURSE: NEW CHALLENGES FOR TEACHERS, STUDENTS, AND THE DESIGN OF CURRICULUM MATERIALS

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Science education reform emphasizes learning science through inquiry as a way to engage students in the processes of science at the same time that they learn scientific concepts. However, inquiry involves practices that are challenging for students because they have underlying norms with which students may be unfamiliar. We therefore cannot expect students to know how to engage in such practices simply by giving them opportunities to do so, especially if the norms for inquiry practices violate traditional classroom norms for engaging with scientific ideas. Teachers therefore play a key role in communicating expectations for inquiry. In this dissertation, I present an analytical framework for characterizing two teachers' enactments of an inquiry curriculum. This framework, based on Gee's (1996) notion of Discourses, describes inquiry practices in terms of three dimensions: cognitive, social, and linguistic. I argue that each of these dimensions presents challenges to students and, therefore, sites at which teachers' support is important for students' participation in inquiry practices.

I use this framework to analyze two teachers' support of inquiry practices as they enact an inquiry-based curriculum. I explore three questions in my study: (1) what is the nature of teachers' support of inquiry practices? (2) how do teachers accomplish goals along multiple dimensions of inquiry?, and (3) what aspects of inquiry are in tension and how can we describe teachers' practice in terms of the tradeoff spaces between elements of inquiry in tension?

In order to study these questions, I studied two eighth grade teachers who both enacted the same inquiry-based science curriculum developed by me and others in the context of a large design-based research project called IQWST (Investigating and Questioning my World through Science and Technology. I found that the teachers provided support for inquiry along all three dimensions, sometimes in ways in which the dimensions were synergistic and sometimes in ways in which the dimensions were in tension. These findings have implications for the design of inquiry science learning environments and for our understanding of what it means for teachers to be “cultural brokers” between students’ everyday experiences and classroom science inquiry.

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CHAPTER ONE
METHODS

Introduction

This study was part of the design of an eight-week inquiry-based, middle-school curriculum focusing on ecosystems and natural selection. The design effort is part of a collaboration called IQWST (Investigating and Questioning our World through Science and Technology) between Northwestern University, the University of Michigan, and Project 2061 to bring together standards-based and problem-based design approaches in middle school curricula. The curriculum, entitled *Struggle in Natural Environments: What Will Survive?* involved students in two major investigations. The first investigation centered around the effects of an invasive species on an ecosystem. Major content goals for this part of the unit were: 1) the relationship between structure and function, 2) the role of competition in survival, and 3) food web interactions. The goal for this investigation was for students to formulate a proposal plan to rid the Great Lakes of the sea lamprey, an invasive species. The second investigation centered around the reasons behind a sudden decrease in a population of ground finches in the Galapagos Islands. Students in this investigation were trying to answer the question "How do populations change over time?". The major content goals for this part of the unit were: 1) differential survival and reproduction, 2) the role of environmental stress on survival, and 3) a basic understanding of the theory of natural selection.

Study Design

The major question addressed in this study was: *what is the nature of teachers' support of inquiry practices as they enact an inquiry-based curriculum*? Specifically, I hoped to understand what aspects of inquiry teachers attend to and how they do so. How and when do teachers communicate the norms for reasoning, interacting, and language use? How explicit is this communication of norms? Given that there are multiple aspects of inquiry for teachers to support at any given moment, what instructional tradeoffs arise and what strategies do teachers have to manage them?

In order to answer these questions, I wanted to carefully analyze an enactment of a curriculum that I knew would have multiple opportunities for students to engage in complex inquiry practices. I also wanted to compare at least two teachers' enactments in order to have the opportunity learn from contrasting cases (Bransford, 1989). Therefore, I analyzed two eighth grade teachers' enactments of *Struggle in Natural Environments: What Will Survive?*. As one of the designers of the curriculum I was closely involved in designing some of the complex inquiry experiences for students, so the pilot test of this curriculum was an opportunity to understand how teachers supported complex inquiry practices.

Study participants

The two teachers, Denise and Sherry, were both located in the same urban public school setting in the Midwest. The design team for the curriculum was familiar with both teachers, as they both had been involved in previous pilot testing efforts of inquiry-based curricula. Because of this previous experience with them, we knew both teachers to be familiar with inquiry-based teaching strategies. However, we also knew these teachers to be neither master nor novice inquiry teachers. These seemed, to me, to be ideal choices for understanding how everyday teachers supported inquiry in their classrooms. Additionally, because I was interested in doing detailed, moment-by-moment analyses of interactions between teachers and students, I chose a case-study approach (Yin, 2003) with a small number of teachers rather than a more survey approach with a greater number of teachers.

Denise and Sherry enacted the curriculum in the spring of 2003. There were 29 students in Denise's class. According to interview data from Denise, 95% of her students were learning English as a second language; however, the students were at varying degrees of proficiency with English. Five of the 29 students attended an ESL class in which they received specialized support for learning English. The class was made up of 14 girls and 15 boys. There were 27 students in Sherry's class. Three of her students had physical and/or mental disabilities as categorized by the school. Two other students in the class attended an ESL class to receive support for learning English. There were 15 girls and 12 boys in the class.

In addition to studying the teachers and whole-class interactions, the teachers selected a focus group of four students for me to study more in-depth. I asked the teachers to select a group of students who were representative of the achievement levels in the class. The curriculum was designed for students to work in groups in almost every lesson. Both teachers divided the students in groups that worked together for the duration of the curriculum. Therefore, the focus students in each class were a group of four students who worked together for the duration of the enactment of the curriculum.

Data collection

In order to conduct careful analyses of the teachers' support of inquiry and to capture teaching practices that were representative of their practice, I observed them every day they enacted the curriculum. The enactment was videotaped daily, and field notes also captured the daily observations. I was a participant/observer in both classrooms and worked daily with the teachers to answer their questions about scientific content and goals of the curriculum. Two cameras were set up in the room, one focused on the teacher and one capturing the whole class and focus group activity. The teacher had her own microphone that fed directly into the "teacher camera" so that as she walked around the room talking to various groups of students, her voice would be captured on the tape. The "student camera" was focused on a wide shot of the class, but when the students worked collaboratively in small groups, the camera captured only the focus students' talk and activity.

Denise and Sherry were each interviewed three times during the unit to understand their understandings of inquiry, the major teaching challenges they and their students encountered during the unit, and their reflections of their students' learning. Focus group students were also interviewed before, during, and after the unit to understand their perceptions of science, of specific scientific practices such as using evidence, analogical reasoning, and analyzing data.

Data analysis

The analysis in this dissertation was based mainly on qualitative analysis of video data and occurred in four main stages. I will describe each of these stages in detail in this section.

Analysis stage one: epistemic practices

Before I could describe the nature of teachers' support of inquiry practices I first asked: what *is* an inquiry practice? I used Collins and Ferguson's (1993) theory of epistemic forms and games as a theoretical lens with which to describe teachers' enactments of inquiry practices. This framework allows for a way to discriminate between the different types of reasoning students do around the same form. Schwarz and Sherin (2002) have expanded on this theory and developed a categorization scheme to articulate the types of epistemic forms and games found in inquiry units. Part of this scheme is shown in Tables 1 and 2.

TABLE 1.Types of epistemic games and their descriptions (based on Schwarz & Sherin, 2002).

Type of Epistemic Game	**Description of the game**
Ordering	Any game in which the order of the variables is significant in understanding the concept. This includes building a narrative in which the order of events is significant.
Identification	Games focused on identifying the important variables of a form and the interactions between them.
Prediction	Games that focus on the results of hypothetical situations, either tracing the effects of changes in variables across a system or projecting events into the future.
Structural Analysis	Games that are focused on understanding the underlying structure of a concept. This includes constructing generalizations about the underlying structure of a concept.
Concept Generation	Games that are used to generated new concepts or to apply a form instance to a new situation.

In this study, I make the distinction between an *inquiry practice* and an *epistemic practice*. I use the term *epistemic practice* as the intersection of the epistemic form and the epistemic game. It is a precise description of a type of reasoning and the form around which that reasoning is done. In contrast, the inquiry practice is a broad description of a complex learning goal. For example, in this curriculum, lessons usually centered around a single form such as a *model*, and teachers supported several epistemic practices around that form in order to enact a complex inquiry practice such as *applying a model*.

I adopted this categorization scheme to have a precise way to code the types of reasoning the teachers engaged students in as they enacted an inquiry practice. I selected five lessons to study that had the potential to be rich sites for teachers supporting students in complex inquiry practices. I transcribed each of these lessons and coded the transcripts at the utterance level for the epistemic practice I saw the teachers supporting. An utterance was a sentence of group of sentences about the same topic. This analysis allowed me to track where epistemic practices began and ended, and the transitions between them. I could then map, within a single lesson, the types of epistemic practices the teachers supported and when.

TABLE 2: Epistemic practices the teachers in this study used to support the inquiry practice of *applying a model*.

Epistemic Practice	**Description of epistemic practice**
Identifying components and relationships in the model	A practice that focuses on important variables in the model and relationships between those variables
Making predictions from the model	A practice that focuses on the results of hypothetical situations using the model, either tracing the effects of changes made to variables in the model or projecting events into the future.
Constructing generalizations from the model	A practice that involves constructing generalizations about underlying relationships in the model.
Using the model in a new context	A practice that involves applying the model to a new context or situation.

Analysis stage two: development of analytical framework

The second stage of my analysis was focused on understanding how teachers communicated the cognitive, social, and linguistic norms of inquiry to students. This analysis occurred in three steps, each of which I will describe in some detail below. The first step of analysis coded for ***dimensions*** into which teachers' practices can be categorized. The second step of analysis coded teachers' practice into ***elements*** within and across dimensions that represent possible sites of dilemmas teachers may face when enacting inquiry lessons. The final step of analysis coded ***strategies*** teachers used to manage these dilemmas.

Dimensions of inquiry

Using the same lessons from my analysis of epistemic practices, I revisited the transcripts to code where I saw teachers supporting cognitive, social, and linguistic dimensions of inquiry.

These dimensions were derived mainly from literature on how students engage in inquiry science learning (Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998); linguistic studies in education (Gee, 1996; Lemke, 1990), and sociocultural studies on how students from underrepresented groups engage with complex scientific practices (Aikenhead, 1996; Rosebery, Warren, & Conant, 1992; Moje, Callazo, Carrillo, & Marx, 2003; Brickhouse, 1994).

I coded utterances from the teachers for whether they were supporting the cognitive, linguistic, or social dimensions. This was a coding scheme that I imposed on the data, so the teachers may or may not have been aware of

Elements of inquiry

The next step of analysis involved categorizing the "elements", within each dimension, that teachers emphasize as they attempted to engage students in inquiry practices. I define "elements" as the demands, within each dimension, for which the teachers provided support to students during their enactments of inquiry lessons. These elements emerged from my noticing that within each dimension, teachers supported norms for inquiry practices such as "claims are followed by reasoning or evidence", or "reasoning needs to be based on some source of evidence". The elements of inquiry within each dimension were broad categories of norms I saw teachers communicating during their enactments. The norms emerged from the data by my first noting all of the episodes in the lessons that represented points at which teachers were supporting students' inquiry, which included both process and content support. These episodes could last anywhere from two lines to ten minutes of dialogue between teachers and students, depending on how long they stayed on the task at hand. Therefore, I did not code episodes in which the teacher was engaged in classroom management or discipline issues, or if the teacher or students' talk was off-task, such as talking about an event that occurred during lunch, unless it was directly related to the task at hand.

Within the episodes in which teachers were supporting inquiry practices, I then looked at all of the exchanges between the teacher and students and inferred the "norm" of inquiry practices they were attempting to communicate either explicitly or through more subtle means such as questioning or modeling. I looked at exchanges between the teacher and students instead of simply the teachers' talk because often the intent of the teacher's utterance is not clear until the student responds and the teacher reacts in some way to that response (Cazden, 1988). The norms that I inferred from these exchanges came from a theoretical understanding of important aspects of inquiry practices based on reform documents (NRC, 1996, NRC, 2000) and literature on the nature of scientific practices (Toulmin, 1958; Reif & Larkin, 1991; Latour & Woolgar, 1986; Longino, 1990). For example, if I saw the teacher asking "why" after a student made a claim, I inferred that the teacher was asking the student for some kind of reason to back up that claim. Having reasoning or evidence to back up a claim is an important aspect of making scientific claims (Toulmin, 1958). Finally, I attempted to group these norms into categories, which became the "elements" of inquiry. For example, if the teachers communicated several norms having to do with understanding aspects of inquiry practices, such as analyzing data, making claims from evidence, and constructing explanations, I grouped these into what I called "understanding the components of inquiry practices". The elements for each dimension, along with example norms that teachers communicated for each element, are listed in Table 3.

TABLE 3: Elements of inquiry within each dimension and example rules that teachers communicated around the elements.

Dimension of inquiry	Elements of inquiry	Example Norms
Cognitive	• Understanding the components	For *understanding the components of*

	of inquiry practices • Reasoning about scientific ideas • Relating scientific ideas to each other	*inquiry practices:* • Claims need to be followed by evidence • There are multiple interpretations possible for the same phenomenon
Social	• Eliciting students' participation • Understanding teachers' and students' classroom roles • Exploring ideas through discussion and debate	For *understanding teachers' and students' classroom roles* • Students' role is to ask for clarification if they do not understand • Questions can be answered by other students, not just the teacher
Linguistic	• Understanding scientific terms • Understanding how to apply scientific language to inquiry tasks	For *understanding how to apply scientific language to inquiry tasks* • Information in representations can be translated into words • There is an appropriate level of specificity to use when describing patterns in the data

Achieving the elements: Teaching strategies

The third step of analysis involved two parts and was motivated by my noticing that Denise and Sherry seemed to use very different strategies for grappling with similar instructional challenges. For example, upon initial observation, both Denise and Sherry seemed to emphasize both *reasoning about scientific ideas* and having students *share their ideas*, but they "looked" very different in doing so. I needed a language with which to describe these differences. Therefore, in the third phase of analysis I attempted to understand *how* the teachers supported elements in each dimension. My goal was to systematically characterize the types of moves that the teachers used to achieve a particular element as described in Table 3. This involved two steps: (1) categorizing the *strategies* teachers used during a turn at talk, and (2) linking those strategies to the elements that teachers were attempting to support. This phase of analysis was important in giving me a way to understand how the teachers attempted to balance elements of inquiry. As I will show later in my analysis, articulating teachers' strategy use gave me a systematic way to describe variation between the teachers and where they fell in the tradeoff space between elements of inquiry that are in tension.

I conducted this phase of analysis by returning to the classroom data and identified episodes in which the teachers were supporting inquiry practices. Then, at each exchange between the teacher and student, I attempted to identify the strategy the teacher was using to support the inquiry practice. For example, was the teacher asking a question? If so, what was she asking for? I conducted this phase of analysis completely blind to the rules and elements I identified in phase two of the analysis, so that I coded the strategies independently from the elements and rules. This was important so that I could ask the question of whether the same strategy could be used to support multiple elements simultaneously. I will discuss this in my analysis.

From this coding, I identified twenty-five strategies the teachers used across the five lessons I analyzed in the unit. I grouped these strategies into six major categories that Denise and Sherry used to communicate rules of inquiry elements. I list the categories of strategies, the specific strategies within each category, and examples from the data in Table 4. The categories shown in Table 4 are adapted from Kelly, et al's (2000) scheme of teacher strategies. In their study, Kelly et al explored the ways in which teachers' discursive strategies could promote students' engagement with scientific ideas. While I let the specific strategies, in the middle column of Table 4, emerge from the data, I found that these moves could be categorized in terms of many of the categories in Kelly et al's scheme. Therefore, I take most of the categories of strategies from Kelly et al's scheme, and adapt others based on data from the teachers. Finally, although the categories shown in Table 4 were useful for helping us understand on a broad level what the teachers were trying to accomplish with each strategy such as "modeling" or "community building", my analysis of the teachers' strategy use will be in terms of the specific strategies listed in the middle column of Table 4 such as "consensus-building" and "introducing/calling attention to relationships".

TABLE 4: Six major categories of teacher strategies, specific strategies within each category, and examples from the data.

Category	Strategies	Example from data
Modeling	Modeling how to use representations to make claims	Denise: Why would the snake decrease? Eric: Because the rabbit population took over. Denise: Ok. Let's look at it. Here it is [shows overhead of graph]. Um, blue is rabbits. You're right. It went way, way up. (lesson 9)
	Modeling scientific language use	Sammy: It went up real high at first and then it cam down and then it stayed the same all the way down. Sherry: So we see peaks, we see valleys, we see the peaks, and they start getting smaller, correct, and then they sort of stabilize. (lesson 9)
Structuring	Introducing/ calling attention to relationships, previous investigations, ideas	Denise: But don't forget—remember what you said about our predictions. Lampreys went in and ate the trout so in the meantime what happened to the whitefish? You said it. Eric: It went up. (lesson 10)
	Mapping between model/ simulation and reality	Denise: Ok if you were a walleye and you got taken out, and I think you have this on your sheet, right? Who do you directly affect? Students: the walleye Denise: No, where does your arrow go towards? If goes towards a couple of places. Alright one that you directly affect is the whitefish. (lesson 8)
	Explaining content	Sherry: This is a producer, it's going to grow, and something eating it will keep that in check. It's not going to overboard, and we're not going to have algae suddenly everywhere. Ok? (lesson 8)
	Consensus-building (orienting students' ideas around each other)	Denise: After 50-60 generations, do most of you agree with Lin that the snakes went up for a while and then stabilized? (lesson 9)
	Asking a chain of closed questions[1] to	Denise: Ok what is the affect if I add that new organism to the food web? So I'm adding what to the Great Lakes now? Larry: Sea lamprey Denise: Sea lamprey. So what happens to the food web?

[1] "Closed questions" are questions that the teacher asks to which she expects a particular response (Cazden, 1988). These are opposed to open-ended questions, in which the teacher has no clear expectation for a particular answer.

	build to a specific idea	S: It'll change? Denise: It'll change. Ok, so what are they prey of the sea lamprey: Students: fish Denise: So what happens to the fish? Students: They'll decrease. (lesson 8)
Probing	Probing to expand	Denise: What do you think happens to the chub? S: Stay the same. Denise: You think it'll stay the same at the beginning and then what might happen? (lesson 8)
	Probing for evidence or reasoning	Sherry: And sometimes the peaks were higher, in the beginning were the peaks or lower and that sort of stabilized or evend out. Did you guys see that? Why do you think that happened? (lesson 9)
	Probing for clarification	Denise: If I attack the perch and then the rest of the fish, what happens to the rest of that food system? Eddy: It decreases. Denise: What decreases? Eddy: All. (lesson 8)
	Asking "why"	Gary: I don't think there'll be a big change. Sherry: Why? Gary: Because it's going to stay, like it's pretty stable. (lesson 9)
Community building	Inviting multiple interpretations	Sherry: Anybody got different things? Anything else? (lesson 10)
	Giving students the floor	Denise: Say it louder Eddy. (lesson 8)
	Giving students credit for their contributions	Denise: Actually, grass went down like somebody said they would, um, Carl said they'd go down for a minute. (lesson 9)
Building on students' ideas	Re-stating students' words	Mike: I put the whitefish go up because the lake trout are decreasing, the lake herring goes up, and since the whitefish eats the herring, the lake herring gives the lake whitefish enough to eat. Sherry: So you think that the whitefish will increase because they have food. (lesson 10)
	Expanding on students' comments	Anna: the snakes are eating the rabbits and the invasive species are competing with them for the grass. Sherry: So they got the snake sill eating them and they got this other organism taking over some of their food source which is affecting them on the other side. (lesson 9)
	Summarizing students' responses	Denise: So some people think—these are the two birds I'm hearing. Some people are saying woodpecker, some people are saying finch. (lesson 3)
	Revoicing students' comments	Sherry: What's a structure? Allison: It's like the kind of tool you use to eat with. Sherry: Ok, so it's what you're using. (lesson 3)
Explicit Support	Defining terms	Denise: Do you directly affect the person next to you, the organism next to you? Larry: Yeah Denise: Direct means, if I'm directly affecting somebody, I'm next

		to them. (lesson 8)
	Translating representations into words	Sherry: [points to overhead of food web] So we've got aquatic plants being eaten by snails being eaten by leeches being eaten by yellow perch being eaten by great blue heron. You guys following that? (lesson 8)
	Defining language use	Denise: You can use more than one word. You can say like there's a sharp increase and then a… S: decrease. Denise: Ok you can stay stuff like that. (lesson 10)
	Defining roles	Sherry: Believe it or not, I'd like you guys to talk to each other about this stuff. It's not just each of you doing your own work. When you get to a question, talk to each other and see what your partners think. (lesson 3)
	Defining processes	Sherry: If you can sufficiently support your reasoning, or show me your reasoning behind why you think—there's no pattern, it falls out of the range—I think that I would, if it was a test question, I would give you credit for it. (lesson 10)
	Defining representations	Denise: So rabbits are blue, what happened to them? (lesson 9)

In the second step of analysis*, I asked the question what was the teacher accomplishing by using a particular strategy?* This step of the analysis was motivated by the realization that simply identifying teachers' moves was not sufficient to understand the complexity of the teachers' practices. I needed to look at the substance of their talk in order to understand what, exactly, they were accomplishing with their particular move. For example, the strategy of asking a chain of closed questions could be used for at least two purposes: to simply drill students on what they already know or to co-construct new ideas with students. The pattern of talk and the structure of a particular strategy may hide the complexity of the work being done by the teacher and students. Therefore, this analysis of the teachers' strategy use also involved mapping the strategy to the specific element of inquiry the teacher was attempting to support. This phase of analysis involved both characterizing teachers' strategy use and understanding what element of inquiry the teacher was supporting with that strategy.

The result of this analysis was an analytical framework that encompasses all three steps of analysis: dimensions, elements, and strategies, each providing an increasingly specific way to characterize how teachers managed dilemmas between the elements of inquiry. The framework is summarized in Table 5. Identifying the elements of inquiry helped to identify the aspects of each dimension that could be in tension with each other. This helped illustrate how that elements within the same dimension and across dimensions could be in tension, and that teachers need to attend to some or all of these elements simultaneously as they support students in inquiry. The third phase of analysis helped to identify both the strategies the teachers used to support the elements of inquiry and the dilemmas Denise and Sherry may have been grappling with.

TABLE 5: Analytical framework showing dimensions, elements, and strategies.

Dimension (Analysis step 1)	Element (Analysis step 2)	Strategy (Analysis step 3)
Cognitive	• Understanding the components of inquiry practices • Reasoning about scientific ideas • Relating scientific ideas to each other	For *understanding the components of inquiry practices*: • Probing for evidence • Asking "why" after a student makes a claim
Social	• Eliciting students' participation • Understanding teachers' and students' classroom roles • Exploring ideas through discussion and debate	For *eliciting students' participation:* • Giving students the floor • Giving students credit for their contributions
Linguistic	• Understanding scientific terms • Understanding how to apply scientific language to inquiry tasks	For *understanding scientific terms:* • Explicitly defining terms • Modeling scientific language use

Analysis phase three: Identifying synergistic moments and moments in tension

In the last phase of data analysis, I was interested in understanding the strategies teachers used to either support multiple dimensions simultaneously (synergistic moments) or how teachers seemed to manage tradeoffs between two dimensions. I identified possible synergistic moments by locating in the data groups of utterances in which teachers seemed to be supporting the same two elements of inquiry. I then looked within that episode to analyze what strategies teachers used to support multiple dimensions of inquiry simultaneously and to what effect. To identify possible points of tension where the teachers were possibly managing tradeoffs, I looked at points in teachers' enactments where they seemed to be supporting multiple dimensions simultaneously but work in one dimension seemed to come at the expense of work in another dimension.

Analysis of interview data with students and teachers

The interviews with students and teachers were analyzed as a way to triangulate the classroom observation data. Therefore, this analysis occurred after I had conjectures about each teachers' practice and how they supported students in inquiry. For example, I noticed in the classroom observations that Sherry relied heavily on elements of the social dimension, such as eliciting students' participation and exploring ideas through discussion and debate, and that this often came at the expense of converging on key ideas in the lessons. In analyzing the interview data, I looked for whether this was a part of Sherry's practice that she was aware of and could speak about. If so, that would strengthen the claims I could make from the observational data.

CHAPTER TWO
ARGUING FOR A MULTIDIMENSIONAL FRAMEWORK FOR DESCRIBING TEACHERS' SUPPORT OF INQUIRY PRACTICES

Introduction: Challenges of teaching and learning science as inquiry

A driving theme in current science education reform is inquiry as a way of teaching and learning science (AAAS, 1990; NRC, 1996). In this study I take inquiry to be a system of practices that engages students in "authentic" investigations into real-world problems as they learn scientific principles. These practices consist of students forming scientific questions, designing experiments or methods for answering those questions, evaluating evidence in light of scientific principles, developing evidence-based explanations, considering alternative explanations, and communicating these explanations for the purposes of justifying them to an audience of their peers—all within the context of an investigation into a real world problem (NRC, 1996; NRC, 2000; Krajcik, Blumenfeld, Marx, Bass, Fredricks, 1998; White & Frederiksen, 1998). In the course of their investigations, students may engage in some or all of these practices, and students may be given more or less freedom to engage in these practices. For example, in a classroom in which the students do not have much experience with inquiry, teachers may choose to include more scaffolding to support students as they engage in inquiry practices. Conversely, students may be given relative freedom to ask and develop their own questions and design their own experiments to answer those questions—with the teacher as a guide and partner in the investigation rather then the authority (NRC, 2000).

Inquiry represents a departure from the vision of traditional school science as a "rhetoric of conclusions" (Schwab, 1966) in which science is merely a body of facts to be memorized. Instead, inquiry science often involves students in collaborative processes in which they jointly design and carry out investigations, analyze data, and construct scientific explanations based on evidence. Inquiry requires students to engage in new types of scientific practices within the context of a complex investigation, thus combining the need for deep content understanding and the skills to conduct meaningful investigations. This often occurs without explicit instruction on how to engage in these practices. Because inquiry represents practices with which students may be unfamiliar, students must not only engage in these practices but also simultaneously learn how to engage in these practices.

Therefore, we as a field need a better understanding of *how* teachers engage students in these complex and unfamiliar practices. What aspects of inquiry practices do they attend to? In what ways do they support students in participating in these practices? What challenges arise for teachers as they enact inquiry curricula? Answering these questions can give curriculum designers and teacher educators principles for designing better supports for teachers in both curriculum materials and professional development opportunities. Understanding how teachers support students in inquiry can help curriculum designers and teacher educators better anticipate and manage the challenges that might arise while enacting inquiry curricula. By looking at both the challenges that arise *and* the strategies that teachers use to deal with those challenges, curriculum designers can build in suggestions to teachers about possible ways to support particular inquiry practices in their curriculum. By looking at what aspects of inquiry practices teachers attend to as they enact inquiry curricula, teacher educators and curriculum designers can better understand the important or challenging aspects of inquiry practices that might need particular attention during an enactment.

In this study, I explore the kinds of challenges inquiry presents to teachers and what happens as teachers attempt to address those challenges. I do not assume that all teachers' attempts to support inquiry are successful. Before we as a field can evaluate the success of teachers' support of inquiry, we need to first identify the challenges teachers face as they enact inquiry curricula and the strategies we see them using to deal with those challenges. Identifying these challenges and strategies will help us better understand what it takes, in a real classroom setting, to support students in inquiry. Only after we have identified these challenges can we then evaluate the effectiveness of teachers' strategy use to meet those challenges. Therefore, in this study I will use a case study approach to explore the challenges that arise for two teachers in their particular instructional contexts as they enact an inquiry-based curriculum. I will present an analytical framework that I will use for understanding what aspects of inquiry teachers attend to as they attempt to support students in inquiry. This framework attempts to capture the complexity of teaching challenges that may arise as teachers enact inquiry curricula and the ways in which teachers may deal with those challenges. As such, it presents one perspective on the types of supports that may need to be in place for teachers in curriculum materials in order for them to better support students in inquiry practices.

I will also explore what teachers' enactments of inquiry curricula may tell us about the challenges teachers perceive students to face in learning how to engage in complex inquiry practices. Which aspects of inquiry do teachers explicitly support and which do students need to infer on their own? In the following sections, I situate this work at the intersection of previous studies done in two areas: (1) pedagogical challenges teachers face in inquiry, and (2) challenges students face as they attempt to engage in complex inquiry practices, I explore each area in turn in the following sections.

Pedagogical challenges for teachers

Teaching science through inquiry is a complex practice that requires teachers to attend to multiple goals simultaneously. There are numerous models for what practices constitute inquiry

(Krajcik, et. al, 1998; White & Frederiksen, 1998, NRC, 1996), what features an inquiry classroom should have (NRC, 2000), and what teachers need to do to support these practices in classrooms—from supporting a community of learners (Engle, 2002) to engaging students in aspects of authentic scientific knowledge construction (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duschl & Osborne, 2002) such as argumentation. Among the existing models of inquiry in the literature, however, there are a few common features that may constitute "ideal" inquiry—a vision of teaching and learning science through inquiry that accomplishes the most ambitious learning goals for students. These include:

- Questioning—teachers engage students in investigating and generating scientific questions about natural phenomena
- Investigating—teachers engage students in investigations in which they explore scientific questions, make claims about scientific phenomena, and gather evidence to support those claims
- Explaining—teachers engage students in analyzing data, drawing conclusions, and constructing evidence-based explanations
- Communicating—teachers engage students in collaborating and communicating their findings with their peers

Of course, these components are integrated with parallel (and, hopefully, complementary) content learning goals. Students ideally learn content in a deeper and more meaningful way by engaging in these processes. The teacher therefore needs to balance not only attention to each of the "ideal" inquiry components listed above but attention to content as well. There are also degrees to which inquiry may be enacted in classrooms. Inquiry may be more or less teacher-directed depending on students' familiarity with content and inquiry practices (NRC, 2000).

Therefore, two teachers may both be described as teaching science as “inquiry” and have very different teaching practices to support inquiry practices, depending on their instructional contexts.

Furthermore, within each of these “ideal” components of inquiry classrooms, there is ongoing research concerning *how* teachers support these in classrooms. Engel (2002), for example, presents a framework for fostering “productive disciplinary engagement” based on principles of Fostering a Community of Learners. His framework includes four components:

- Problematizing: students are encouraged to take on intellectual problems,
- Authority: Giving students the authority to address problems,
- Accountability: student are accountable to others,
- Resources: students are given adequate resources to do all of the above.

One can imagine that teachers would need to provide support in all four components in order to accomplish the ideal inquiry goals stated above. For example, students need to have opportunities to *problematize* in order to engage with scientific questioning. This may involve helping students understand the nature of scientific questions and the ways in which scientists usually explore these questions. Students need to be given the *authority* to address those problems as they design and carry out their own experiments. This may require drastically re-negotiating the social structure in the classroom so that the teacher is not the sole authority, but instead shares the authority with her students. Also, students’ explanations for phenomena need to be *accountable* to their peers and open to critique in order for students to engage in the social knowledge construction that is crucial to scientific practices. Students need to have the expectation that their ideas will be taken seriously and that discussion of ideas is intellectually productive. For example, by communicating their explanations to their peers, students may be forced to consider alternative explanations and revise their own. Finally, students need to have adequate *resources* of time, materials, and access to experts in order to accomplish all of the "ideal" inquiry components listed above.

Teaching inquiry therefore involves many components for teachers to put in place in classrooms: challenging cognitive experiences in which students may reason about scientific ideas and productive social experiences for students to be accountable to others. How do teachers accomplish these and what does it look like in classrooms when they do? In order to answer this question, it may be helpful to look at recent research into teachers' enactments of inquiry-based curricula in both mathematics and science that suggests that teaching is more accurately described as managing dilemmas and working within tradeoff spaces rather than making clear-cut decisions (Sandoval & Daniszewski, 2004; Windschitl, 2002; Lampert, 1995; Ball, 1993). For example, Sandoval and Daniszewski (2004) found teachers in their study to be grappling with several tensions or tradeoffs in their enactments of an inquiry-based high school science curriculum. Among these were tensions between exploring students' ideas and review of formal ideas in the curriculum, student versus teacher-led discussions, and teacher as guide versus teacher as authority. These tradeoffs can occur as teachers attempt to enact any one of the five ideal inquiry components listed earlier. For example, as teachers allow students to investigate their own scientific questions, they need to carefully consider how much freedom they need to give students to pursue their own questions and how much input the teachers themselves should give.

Therefore, because inquiry involves balancing multiple demands—process versus content, teachers and classroom roles, structured versus open inquiry strategies—teachers necessarily need to make strategic choices about what aspects of inquiry to emphasize and when.

The notion of working within tradeoff spaces is a useful one for understanding both the source of challenges for teachers and their strategies for dealing with those challenges as they enact inquiry curricula. One can easily imagine that important aspects of inquiry may at times be in tension, such as emphasizing students' independent roles in investigations but also needing to cover the content at hand. How a teacher manages these tensions may depend on, among other things, her perception of students' needs, her understanding of inquiry practices themselves, constraints of her instructional context, and her comfort level with the content ideas. In this section I will explore two examples of tradeoffs that teachers may grapple with as they enact inquiry curricula: balancing content and process goals, and balancing the need for structure and freedom to explore ideas.

One of the major challenges for teachers as they enact inquiry curriculum is balancing attention to content ideas and engaging students in inquiry practices. Inquiry involves students in learning deep content ideas *through* participation in complex practices such as forming explanations and defending those explanations to their peers. Teachers must therefore support students not only in learning scientific content ideas but also in learning how to engage in complex practices that may differ dramatically from classroom or school practices with which students may be more familiar (Roth, McGinn, & Bowen, 1996). One pedagogical challenge in supporting both content and process goals is to avoid teaching strictly procedure or teaching for one "right" answer. Students and teachers can get caught up in learning procedures for a particular investigation, thereby having an activity devolve into a "cookbook" laboratory rather than an open-ended investigation into a question. Furthermore, inquiry investigations often involve more than one answer depending on the nature of the evidence students gather. Teachers need to emphasize the importance of justifying one's answer based on scientific principles rather than on getting the right answer. However, it is a challenge to balance these process and content goals simultaneously in the classroom while still giving students a sense for procedure and appropriateness of answers. We can see from studies in mathematics where teachers attempt to teach mathematics for understanding, that even teachers who are well aware of the importance of deep mathematical concepts for understanding procedures often fall back on procedural teaching techniques (Eisenhart, Borko, Underhill, Brown, Jones, & Agard, 1993). Eisenhart, et al (1993) found that factors such as pressure to cover all topics in a curriculum, a teacher's own mathematical knowledge base (or lack thereof), and a teacher's perceptions of the needs and interests of her students may all contribute to a teacher devoting more time to teaching procedures rather than underlying mathematical concepts. In previous work with inquiry science teachers, we have found that a teacher can fall back on emphasizing procedure over underlying scientific principles, even when that same teacher emphasized open-ended questions and relative freedom in previous lessons (Tzou, Reiser, Spillane, & Kemp, 2002). Therefore, teachers need to carefully balance the need for guidance in learning procedures for new practices and emphasizing the connection of those practices to underlying scientific ideas.

Another challenge for teachers in teaching for deep understanding involves balancing the need to let students explore ideas independently and knowing when to intervene and provide guidance (Chazan & Ball, 1999). As I mentioned earlier, teachers can allow students more or less freedom to pursue answers to their own questions, to devise methods for gathering data, to analyze data, and to construct explanations. However much freedom a teacher allows, she needs to carefully evaluate her own role in the classroom and how that might change as students take on more responsibility for their own learning. For example, inquiry investigations are often so complex that different students may take on different aspects, thereby taking individual responsibility for part of the investigation but distributing expertise through the whole group (Brown, Ash, Rutherford, Nakagawa, Gordon, & Campione, 1993). In this case, the teacher's role is as a guide instead of the sole authority, asking questions at key times and introducing key pieces of content to scaffold students' investigations (Chazan & Ball, 1999). This type of role may be unfamiliar to how many teachers learned science and how they are accustomed to teaching science. Teachers need to carefully balance the need to cover the content and let students inquire on their own (Hammer, 1997) instead of always being the authority or simply letting students pursue any investigation. Curriculum materials need to provide supports for teachers and give them suggestions for how to both support students' independence during investigations but at the same time be a guide to help bring students back to the important scientific ideas at hand. Simply telling teachers not to "tell" students the right answer is only helpful to teachers if productive alternative pedagogical strategies can be suggested in its place (Chazan & Ball, 1999).

From these studies, we can see how teachers' practice may "look" very different from lesson to lesson based on the choices they make in different tradeoffs that might arise during inquiry. For example, a teacher might perceive her students to need a lot of structure in engaging in a practice such as constructing graphs, but in a brainstorming activity that same teacher may provide a lot of freedom for her students to explore different ideas. Teachers need to balance multiple demands simultaneously, making choices about their own and their students' roles as they do so. The notion of teaching as managing tensions can therefore explain some of teachers' practices during inquiry. We also know that there are multiple factors that may influence the ways in which teachers manage teaching tensions that may arise. What we need, however, is a model for where these tensions come from and how teachers manage them. Which tensions seem to arise for teachers as they enact inquiry curricula and why do they arise? What strategies do teachers use as they attempt to balance multiple demands of inquiry? Given a teacher's instructional context, what aspects of inquiry does she emphasize? For example, does she attend to process and content separately, or does she manage to emphasize them simultaneously? How and when does she provide guidance to students as they engage in inquiry practices? How explicit is she in this guidance?

In this study I will present an analytical model for characterizing and explaining the challenges that arise for teachers as they enact inquiry curricula in terms of teaching tensions and the ways in which teachers attempt to manage these tensions. I will use the list of "ideal" inquiry components listed earlier in this section to illustrate how my analytical framework allows us to understand what it takes to put inquiry in place in classrooms. As I will describe later, in this study I explore in detail two teachers' enactments of an inquiry-based curriculum in order to gain an in-depth understanding of their teaching practices as they attempt to deal with the challenges that inquiry poses. While I will not be using the framework to measure teachers' "success" or "failure" at teaching inquiry, my goal in this work is to understand teachers' attempts at inquiry-based teaching—what happens in these enactments and how do they attempt to manage the varied and multiple demands that inquiry poses to them and their students. I will evaluate the teachers in terms of the aspects of inquiry they emphasize and balance as well as the strategies they use to do so. In later work, I explore the possible consequences of those strategies on students' engagement with inquiry practices and content ideas.

Challenges for students

In order to gain a better understanding of where these teaching tensions come from, it is useful to understand the challenges that may arise for students in inquiry. The pedagogical challenges for teachers are made even more complex because of the need to address the challenges they perceive their students to face as they engage in learning science through inquiry. Because inquiry practices have underlying epistemologies that include characteristic and unfamiliar ways of thinking about the world, students may encounter challenges on multiple levels during inquiry. By engaging in open-ended, collaborative investigations, students experience science as much more than a collection of facts and confirmatory experiments (Driver, Newton, & Osborne, 2000). Students must form new cognitive models for what it means to do science. Krajcik, et al (1998) found that in students' initial attempts at inquiry, they often engaged in scientific practices in superficial ways. For example, when reporting results, students tended to report on what they did instead of what they learned as a result of their investigations. Furthermore, inquiry requires students to use deep content knowledge in order to engage in scientific practices (Edelson, Gordin, and Pea, 1998). In order to understand what results to report on, students must interpret the data they collect in light of relevant scientific principles. Finally, inquiry investigations are often complex and lengthy, requiring students to keep track of their progress (White and Frederiksen, 1998). This requires students to not only engage in challenging inquiry practices that require both content and process skills, but students must also periodically reflect on what they have learned in order to make decisions about the next steps in their investigations.

However, many studies of students doing inquiry have focused mainly on the cognitive aspects of inquiry practices (Krajcik, et al., 1998; White and Frederiksen, 1998) such as students' understandings of the types of reasoning involved in an inquiry practice. Although this is certainly a significant challenge, I argue that it may not be the only challenge for students in inquiry. Inquiry investigations also involve new social roles for students in classroom, and these roles may violate traditional classroom norms. For example, students often work collaboratively on an investigation, with different students investigating different aspects of a problem. Students must make joint decisions about the direction of their investigations. This requires students to depart from the more traditional roles that they often take on in school activities in which a teacher instructs them on exactly which steps to follow and in what order. In this way, the social environment of the class changes from having one authority (the teacher) to sharing authority among the students, teacher, and outside experts.

Inquiry practices, representing the more authentic practices of scientists, are also social by their very nature (Longino, 1990). In order for knowledge construction to occur in science, scientific findings are made public, open to critique and argumentation. Inquiry curricula often attempt to mimic this process in the form of public presentations in which students' findings are shared with the class for critique and discussion. This social aspect of inquiry practices is perhaps one of the most dramatic differences between students learning out of a textbook and students learning science through inquiry: rather than individually answering questions from a book or writing up a lab report, students are put into roles in which they present and defend the findings of their investigations. Therefore, they not only go through the cognitive reasoning involved in conducting their investigations, but they also engage in the social aspects of the practice as well.

Finally, having the opportunity to interact with other students in new ways involves a certain type of language use in science. In science, as in other disciplines, language use implies certain norms of action; therefore, learning to use the language of science means, in part, coming to learn how language can be translated into certain actions (Lemke, 1990). Students come to the classroom with their own ways using language that might be different from scientific ways of using language. Because teachers might already be familiar with norms for scientific language use, they may not realize how their language use reflects certain beliefs, values, and actions that students are unfamiliar with (Rosebery, Warren, and Conant, 1992). In inquiry classrooms, terms such as “hypothesis” and “explanation” are often used as if they were transparent without the teacher or curriculum materials supporting students in understanding how they are specialized constructs in science.

Inquiry practices are complex. They present cognitive, social, and linguistic challenges to students. Furthermore, as teachers attempt to support students during inquiry, they need to understand the ways in which inquiry practices may be challenging to students. As with any instructional reform effort, inquiry strongly depends both on the practices of teachers as they interact with these materials and the interactions between teachers and students (Cohen & Ball, 1999). The ways in which teachers enact inquiry practices may vary based on their understanding of inquiry, their content knowledge, or their particular classroom contexts (Songer, Lee, & McDonald, 2003). Inquiry is therefore not a monolithic set of practices; instead, it involves teachers in providing more or less guidance for inquiry practices depending on their instructional context.

Summary

In this study I present an analytical framework for describing teachers’ attempts to support students in inquiry practices. From existing literature on challenges students may face during inquiry practices, my framework outlines three dimensions along which teachers may need to provide support as they engage students in inquiry: cognitive, social, and linguistic. I will discuss each of these dimensions in more detail in later sections. However, because each dimension presents multiple challenges to students that are important for teachers to attend to, I can use the framework to which aspects of inquiry teachers emphasize and how they do so. I will also describe how the framework can identify aspects of inquiry that may be in tension and the tradeoff spaces within which teachers may be working as they attempt to support students in inquiry. The framework offers us a perspective with which to describe what it takes to operationalize inquiry practices in the classroom: which aspects of inquiry teachers emphasize and the strategies with which they emphasize them. Curriculum designers and teacher educators can then use this description to understand potential challenges that may arise for both teachers and students and use these findings on teachers' strategy use to build in better supports for teachers (and students, in the case of curriculum designers) to deal with those challenges.

Given that teachers' support may involve attending to social, cognitive, and linguistic challenges that arise for students learning how to engage in inquiry practices, I explore in this study how teachers address these challenges. For example, given the need to balance process and content goals and the additional challenge that students are unfamiliar with *both* the scientific ideas and the underlying epistemologies of scientific inquiry practices, what does a teacher emphasize? What strategies does she employ and how can we describe where she is in the tradeoff space between these goals? How does a teacher make students aware of epistemological demands of an inquiry practice while still attending to the important scientific ideas? How explicit is the support teachers provide?

Research Question

In this study, I build on previous research into challenges for both teachers and students as they engage in inquiry. I hope to understand on an empirical level how teachers attend to the multiple, often competing challenges that arise during inquiry. In the process, I also hope to better understand the challenges students face in learning how to engage in inquiry practices and how teachers and curriculum materials can address those challenges so that students who are unfamiliar with inquiry practices can successfully participate in them.

I hope to learn, through teachers' enactments of this unit, what it takes to support inquiry practices in classrooms. I ask the question: *what is the nature of teachers' support of inquiry practices as they enact an inquiry-based curriculum*? Specifically, I hope to understand what aspects of inquiry teachers attend to and how they do so. Which aspects of inquiry do teachers emphasize and when are they emphasized? How and when do teachers communicate the norms for reasoning, interacting, and language use that inquiry practices entail? Furthermore, given that there are multiple goals of inquiry, I will also use my framework to empirically describe and explain both the tensions that arise as teachers enact an inquiry curriculum and situate teachers in tradeoff spaces between aspects of inquiry that may be in tension. Although this study is of just two teachers teaching the same inquiry curriculum, it is a first step in understanding how we can build better supports into curriculum materials and professional development opportunities to help teachers anticipate and manage the many challenges that might arise as they enact inquiry curricula.

In the following sections, I will first present an analytical framework that characterizes the multiple dimensions of inquiry practices as I described above. I will explore how well this framework helps to explain how tensions arise during teachers' enactments of inquiry curricula and will help describe how teachers manage those tensions. By closely analyzing the ways in which teachers support inquiry practices in classrooms, we can better understand both the challenges inquiry introduces for students and the ways teachers address those challenges. Finally, we can deepen our understanding of the complexity of inquiry practices and the types of supports we can build into inquiry-based curricula.

Building a framework for describing inquiry practices, Part I: Inquiry as a Discourse

Inquiry practices such as forming a research question and evaluating hypotheses in light of data have important cognitive elements that students must understand, but they also have underlying epistemologies that include characteristic and potentially unfamiliar social and linguistic elements. These are often tacitly assumed but seldom explicitly taught during inquiry investigations. I argue that it is this multidimensional nature of inquiry practices that makes them so complex and potentially difficult to learn. In this study, I hope to empirically describe the multidimensionality of inquiry practices as they are enacted. In classrooms, do teachers and students attend to multiple dimensions of inquiry practices as they engage in them? If so, which dimensions and how are they interrelated? In order to answer these questions, we first need a theoretical model of how the multiple dimensions of inquiry practices interrelate in inquiry science. We can then test this model against teachers' enactments of inquiry practices to see how well it does or does not capture the complexity of inquiry practices as they are enacted in classrooms.

The first part of my framework comes from taking the perspective that inquiry science represents practices in the Discourse of science, and that these practices present challenges to students on multiple levels. I build on the idea of a Discourse from Gee (1996) in which he argues that a Discourse includes not only ways of talking but also values, beliefs, and ways of interacting with the world that are used by a particular social group[2] (Gee, 1996). Gee argues that "Discourses are ways of being in the world…which integrate words, acts, values, beliefs, attitudes, and social identities" (p. 127). I argue that because inquiry science attempts to approximate authentic practices of scientists, inquiry practices implicitly encompass values or

[2] This is opposed to discourse with a lower-case "d" which signifies any stretch of language. This distinction is important because we wish to emphasize the cultural demands of doing inquiry science as opposed to simply the technical demands of reading and writing science.

norms of reasoning, interacting, and using language that are shared by scientists. Aikenhead (1996) argues that learning science is a process of "culture acquisition" (p.5). For many students, learning science is like learning another culture. There are norms for practices in the Discourse of science that may be largely unfamiliar to most students. I argue that students face challenges in engaging in inquiry practices because of their unfamiliarity with these norms. The question, therefore, is how students learn these norms and what teachers do to help students learn them.

As students engage in inquiry practices, they learn not only new ways of reasoning about the world (cognitive elements) but also social and linguistic elements that are often imbued with epistemologies valued by science as a discipline. I call these cognitive, social, and linguistic elements of inquiry practices *dimensions* of inquiry. I argue that the norms students need to learn in order to engage in inquiry practices can be characterized in terms of these three dimensions.

For example, Krajcik et al. (1998) found that students had difficulty presenting their findings at the end of an inquiry investigation because they tended to present what they did instead of what they learned. Furthermore, the students did not use the presentations as an opportunity to synthesize what they had learned, thereby missing the opportunity to advance their own and the class's understanding of the science content encompassed in the investigations. These findings suggest that students need to refine their cognitive models for what it means to engage in inquiry practices such as presenting one's findings or forming conclusions from evidence in an investigation. I define the "cognitive" element of inquiry practices as aspects of the practice involving reasoning strategies for engaging in a specific practice. For example, backing up a claim with evidence would be a cognitive element of making a scientific claim. The cognitive dimension also involves reasoning about scientific content ideas. Although the term "cognitive" can be applied to many types of activities, in this study I limit my use of the term to apply to scientific reasoning during a particular inquiry process and reasoning about content ideas.

In addition, inquiry curricula tend to be project-based in an "authentic" context (Krajcik et al., 1998). Instead of merely consumers of knowledge, students take on new roles as generators of knowledge (Brickhouse, 1994). Instead of being told by the "expert" teacher what facts they should memorize, students—through investigations they design—construct relevant scientific knowledge for themselves. This involves learning rules in the social dimension of inquiry for what it means to actively participate in a scientific investigation versus being a passive listener during a lecture. I define the “social” element of inquiry practices as that which involves the roles for teachers and students in a particular practice. For example, co-constructing an explanation with the teacher puts students in a particular role that differs dramatically from the science-teacher-as-authority role in traditional science teaching.

Inquiry practices also involve the social dimension because the practices themselves are necessarily social. Longino (1990) argues that the construction of scientific knowledge necessarily occurs within social contexts. For example, in the peer review process, scientists critique each others’ work and decide which studies receive funding, which studies are published in journals, and, consequently, which studies may lead to established scientific knowledge. Furthermore, scientists build on each others’ work—for example, in trying to confirm and refute each others’ findings or by taking a finding and building experiments based on those findings. Inquiry practices such as having students present their findings to their peers mimic some of these social processes by putting students in roles in which they critique each others’ work or question the merits of certain assumptions or arguments. Argumentation, or having students debate about next steps in an investigation or the strength of certain pieces of evidence for supporting a claim, is an example of a social aspect of scientific knowledge construction—through collaboration, competition, and debates in journals, scientists continually argue about theories and the evidence to support or refute those theories. The challenge for teachers, therefore, is how to redesign the social structure in the classroom so that students may take on roles where they are able to engage in the social nature of these practices.

However, engaging in the social aspects of inquiry practices necessitates a certain type of language use in science. Lemke (1990) argues that one of the most difficult aspects of learning science is learning to use the language of science, to "talk science". Talking science, according to Lemke, involves not only understanding the specialized ways in which science uses patterns of speech, grammar, and vocabulary. In science, as in other disciplines, language use implies certain norms of action; therefore, learning to use the language of science means, in part, coming to learn how language can be translated into certain actions. The ways that language is used in scientific Discourse also reflect certain values and beliefs about the world. Halliday (1998) argues that grammar is both a "theory of human experience" and "an enactment of interpersonal relationships" (p.185). The grammar of science therefore reflects certain ways of experiencing the world—through logical reasoning, experimentation, and skepticism—as well as ways of interacting with others. In fact, the ways that students are often asked to construct laboratory reports or scientific artifacts follow a certain structure that reflect logical reasoning processes: state premises first and then conclusions followed by evidence for those conclusions (Lemke 1990). In my framework, the linguistic dimension involves scientific ways of using language. This could mean defining a scientific term or process, modeling ways to use language when analyzing data or communicating scientific ideas, and translating representations into words.

An example of an inquiry practice that involves all three dimensions is constructing and sharing a scientific explanation based on evidence. Aspects of this practice in all three dimensions are summarized in Table 6. This practice often comes at the end of a long investigation in which students have collected and analyzed data in order to answer an open-ended question. In inquiry, an explanation often involves a claim, evidence to back up that claim, and reasoning that links the claim to the evidence (Toulmin, 1958). Participating in this practice requires that students not only understand what the linguistic terms "claim", "evidence" and "reasoning" mean in science, but they must have a cognitive model for what counts as claim, evidence, and reasoning within the context of the investigation. The scientific terms therefore become tools for students to reason about various components of their investigations. Although the cognitive and linguistic dimensions seem very related, I actually consider them separate dimensions. The difference is between knowing the definition of a term such as "claim—which would fall under the linguistic dimension, and knowing how to reason with that term in the context of an investigation. Finally, the practice of students sharing their explanations with their peers means understanding norms for social interaction. These may include norms such as the role of a listener in a discussion is to ask questions and challenge the presenter.

TABLE 6. Example inquiry practice of constructing and sharing a scientific explanation. Summary of possible cognitive, social, and linguistic rules for this practice.

Dimension	Possible Rule
Cognitive	• Claims must be backed up with evidence • Evidence for a claim must come from the data
Social	• As you listen to others' explanations, your role is to be a critical listener and ask questions to challenge the presenter • Questions should be based on the merit of the evidence rather than personal attacks on the presenter
Linguistic	• "Evidence" is what you use to back up your claim

As part of the Discourse of science, inquiry practices contain values and modes of action that students may not be familiar with. If students do not understand the “rules of the game”, they may have difficulty engaging in these practices. The model of inquiry as involving cognitive, social, and linguistic dimensions allows one way to describe the sources of tensions that may arise as teachers attempt to support students in inquiry practices. Teachers need to attend to the demands that arise from each dimension, demands that might sometimes be in tension with each other. For example, providing explicit linguistic support may take class time away from students interacting with each other and sharing their ideas. In this study, I ask: what is the nature of teachers’ support of inquiry practices as they enact an inquiry-based curriculum? In answering this question, I hope to understand certain aspects of teachers’ support as it pertains to my model of inquiry. For example, do teachers provide support along all three dimensions as they enact inquiry practices? Which dimensions do teachers emphasize and when are they emphasized? How and when do teachers communicate the norms for reasoning, interacting, and language use that inquiry practices entail?

I will attempt to answer these questions by looking at two teachers’ enactments of the same inquiry-based curriculum and characterizing their support of specific inquiry practices. However, in attempting to characterize these teachers’ practices, I realized that I needed a more precise way to describe the inquiry practices themselves. In the next section I will describe how I use the perspective of epistemic forms and games to build the next part of my model of inquiry practices.

Building a framework for describing inquiry practices, part 2: Inquiry practices and Epistemic practices

Another challenge in teaching inquiry is making sure students have enough support students in inquiry processes while making sure students get to the more ambitious and challenging parts of an inquiry practice. The second part of my model of inquiry attempts to describe how teachers provide this support by breaking down inquiry practices into smaller, more manageable *epistemic practices*. As I will explain in this section, the perspective of epistemic practices affords a specific language with which to describe where teachers provide support for inquiry practices, at what points they may become "stuck", and what the more challenging aspects of the inquiry practices may be.

The goals for inquiry as stated in reform documents such as *The National Science Education Standards* (NRC, 1996) are broad and ambitious. More careful analysis still needs to be done in order to translate these goals into specific curriculum designs and supports for teachers. For example, one of the inquiry standards for students in grades five through eight states that students should "develop descriptions, explanations, predictions, and models using evidence" (NRC, 1996, p.145). This single inquiry standard asks students to work with many aspects of scientific reasoning: descriptions, explanations, predictions, and models. If we take just one of these, modeling, the standard is still very broad. What does it mean to "develop" a model using evidence? One can imagine building a model from scratch, having part of a model articulated and filling in the rest based on evidence, or running the model and predicting future effects based on current evidence. Although ambitious in nature, inquiry standards as stated in *The National Science Education Standards* leave much of the work to designers and teachers to elaborate these complex practices in order to clarify what types of reasoning are involved and to break down these practices into smaller steps that learners can understand within the context of scientific investigations. The question then becomes: what does this look like in classrooms?

In Chapter One, I described the first stage of analysis: adapting Collins and Ferguson's (1993) theory of epistemic forms and games as a theoretical lens with which to describe teachers' enactments of inquiry practices. This framework allowed me a way to discriminate between the different types of reasoning students do around the same form (see Tables 1 and 2).

This perspective served several purposes. As I mentioned above, it helped me more specifically describe the reasoning steps teachers were supporting. It also allowed me to identify any changes teachers made to the written curriculum in their support of a particular inquiry practice. I found teachers to elaborate on a single inquiry practice using several epistemic practices in order to make the inquiry practice more accessible to students. In doing so, they added epistemic practices that were not in the curriculum. Finally, it allowed me to pinpoint where in an inquiry practice teachers might get "stuck"—at what point teachers might stop before they reach the more ambitious parts of the practice. For example, if students have trouble with the definition of a certain term, teachers may get stuck in the *identification* practice without ever moving to the more ambitious *constructing generalizations* practice.

Taken together, our two perspectives of inquiry as a Discourse and epistemic forms and games helped me to describe the complexity of inquiry practices and may help explain how and why teaching tensions arise. Epistemic forms and games gave me a framework for breaking down complex inquiry practices into constituent epistemic practices. Once I did this, I could then attempt to describe teachers' support of these constituent practices in terms of cognitive, social, and linguistic dimensions. For example, while it might have been possible to describe the cognitive, social, and linguistic rules for the broad practice of *applying a model,* I could better understand teachers' support of this practice if I first articulated the epistemic practices within *applying a model* and then described the cognitive, social, and linguistic supports for each of those practices. Therefore, my model of inquiry practices involves constituent epistemic practices such as *making predictions from a model*, each of which may have cognitive, social, and linguistic elements. Table 4 illustrates this with a sample inquiry practice of *applying a model*. The empty cells would be filled in with the rules teachers communicate at each dimension and the strategies that use to communicate those rules. Using this matrix to analyze teachers' support of inquiry practices, we can then understand both the constituent epistemic practices teachers use to elaborate an inquiry practice and the rules they communicate for each dimension.

By articulating both the epistemic practices teachers enact and the cognitive, social, and linguistic aspects of each of those practices, we begin to gain an understanding of the multiple demands teachers need to balance as they enact inquiry practices. Teachers need to balance how much time they spend on each epistemic practice in order to make sure they eventually engage students in the more ambitious parts of the broader inquiry practice. However, they need to weigh this against their students' needs and their familiarity with engaging in these practices. Within each epistemic practice, teachers need to communicate rules of the cognitive, social, and linguistic dimensions to students. The extent to which they emphasize each dimension may be affected by the needs of their students, their own understanding of both the content and the inquiry aspects of the practice, and other constraints of their instructional contexts.

TABLE 7. Sample matrix showing my model of inquiry practices as it applies to *applying a model*.

<table>
<tr><th colspan="10">Epistemic Practices</th></tr>
<tr><td rowspan="5">Dimension of Inquiry</td><td></td><td colspan="2">Identifying components and relationships in the model</td><td colspan="2">Making predictions from the model</td><td colspan="2">Constructing generalizations about the model</td><td colspan="2">Application of the model to a new context</td></tr>
<tr><td></td><td>Norm</td><td>Strategies</td><td>Norm</td><td>Strategies</td><td>Norm</td><td>Strategies</td><td>Norm</td><td>Strategies</td></tr>
<tr><td>Cognitive</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Linguistic</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

In the following sections, I will first describe the context of my study and then use this model of inquiry practices to describe the ways in which the teachers in my study supported inquiry practices in their classrooms. I ask the question: *what is the nature of teachers' support of inquiry practices as they enact an inquiry-based curriculum*? I attempt to answer this question by analyzing teachers' enactment of an inquiry-based curriculum using the two theoretical perspectives discussed above. I will first use the perspective of epistemic practices to describe how teachers help students engage in complex reasoning tasks during inquiry. I will then use the perspective of inquiry as a Discourse to analyze the ways in which teachers' support of inquiry practices can be characterized in terms of cognitive, social, and linguistic dimensions. The goal of this study is to articulate an analytical framework for understanding how teachers address the multidimensional challenges of inquiry practices.

Based on the two-part model of inquiry practices that I presented above, I will explore two aspects of teachers' support of inquiry practices: the first will be the ways in which they break down the practices into smaller epistemic practices, and the second will be the dimensions of inquiry that they emphasize within each of those epistemic practices. Because my goal in this study is to explore the nature of teachers' support as they attempt to engage students in inquiry practices, I will compare two teachers' enactments of the same inquiry-based curriculum. However, one of the teachers in this study, Sherry, was only able to enact the first half of the unit. Therefore, for this study, I analyzed only the lessons in the first half of the unit for both Denise and Sherry.

Summary of lessons and two-step data analysis

As I mentioned, I was only able to compare the teachers on lessons in the first half of the unit. Table 8 shows a summary of each lesson including the target content and inquiry goals. Because I participated in the design of the *Survive* curriculum, I targeted specific lessons that I thought had the most potential for interesting inquiry activity to emerge: lessons 3, 5, 8, 9, and 10. For each of these, the entire lesson was transcribed and my analysis involved two steps. The first was to describe the epistemic practices that comprised each target inquiry practice and the order in which these epistemic practices occurred. This gave me a precise description of the process by which the teachers were breaking down the larger inquiry practices into smaller "pieces". The second part of the analysis was to look within an epistemic practice and describe teachers' attempts to support that practice in terms of cognitive, social, and linguistic dimensions.

TABLE 8: Summary of the first half of the *Survive* unit, including both content goals and target inquiry practices for each lesson.

Lesson number/Title	Summary	Lesson length (in days)	Target content learning goal	Target Inquiry practice (if applicable)
1: Invasive species—Friend or foe?	Introduction to invasive species/sea lamprey problem	2	Definition of invasive species; effect of invasive species on humans	N/A: setting the context of the investigation

2: The sea lamprey—background to an invasion	Mapping out sea lamprey's route from Atlantic Ocean to Great Lakes	1	Explaining how the sea lamprey was able to invade the Great Lakes	Data interpretation
3: Birds and Beaks	Simulation of birds' beaks with tools in different environments with different food sources	1	Structure/Function relationship; How structure, function, and environment all affect survival	Applying a model
4: Fish and Feeding	Observation of external features of sea lamprey and yellow perch	2	Structure/Function relationship; How a fish's structures help it in feeding	Making observations
5: Reproduction	Reading about long and short life reproducers	1	Reproduction and survival; explaining how an organism's reproductive pattern leads to different survival patterns of offspring	Constructing an explanation
6: Lamprey reproduction—short life or long life reproduction	Finding out what kind of reproducer the sea lamprey is	1	Explaining how the lamprey's reproduction pattern enabled it to outcompete other organisms	Constructing an explanation
7: Food chains	Food chains	1	Relationships between organisms in an ecosystem (predator/prey, producer/consumer)	Making predictions
8	Food webs	2	Relationships between organisms in an ecosystem (predator/prey, producer/consumer); Interdependence of organisms in an ecosystem	Applying a model
9: Individuals and Populations	Net LOGO simulation	2	Describing stability in a population; How individual organisms can affect whole	Applying a model Data Analysis

9: Individuals and Populations	Net LOGO simulation	2	Describing stability in a population; How individual organisms can affect whole populations	Applying a model Data Analysis
10: How has the sea lamprey affected the Great Lakes food web?	Analysis of data from Great Lakes to determine affect of sea lamprey on fish populations	1	How the sea lamprey affected the trout, chub, and whitefish populations in the Great Lakes	Data analysis
11: How can we stop the invasions?	Formulating plan to rid Great Lakes of sea lamprey	1	Describing a variety of ways to stop biological	Constructing scientific explanations

For the second part of my analysis, I coded each utterance the teachers made within an epistemic practice as pertaining to the cognitive, social, or linguistic dimensions. I then looked again at each utterance to determine what the teacher was attempting to accomplish within the relevant dimension. For example, if an utterance was coded as pertaining to the "cognitive" dimension, I would ask what types of reasoning the teacher was attempting to support, or what piece of content was she emphasizing. In the following section, I describe Denise and Sherry's enactments of two inquiry practices: applying a model and data analysis.

Analysis of teachers' enactment of inquiry practices

There were two phases in my analysis of classroom observations and field notes. The first phase involved understanding the ways in which teachers attempted to support students' participation in inquiry practices through epistemic practices. The second phase of my analysis involved using my perspective of inquiry as a Discourse to describe the aspects of inquiry practices teachers emphasized in terms of cognitive, social, and linguistic dimensions. The goal of my analysis was to use the framework articulated in Table 4 as a way to explain teachers' enactments of an inquiry-based curriculum in terms of balancing multiple demands. I will describe Denise and Sherry's enactments of the inquiry practice of *applying a model* below.

Applying a model: The Great Lakes food web

As I described above, the goal for students in Part I of the unit was to formulate a proposal to rid the Great Lakes of the sea lamprey, an invasive species preying on large fish such as trout. In order to formulate their plans, students needed to first understand the effects of the sea lamprey on the Great Lakes ecosystem. Towards the end of Part I, students were introduced to the Great Lakes food web in order to 1) understand the relationships between species in the Great Lakes before the introduction of the sea lamprey and 2) predict and then analyze the effects of the sea lamprey on the Great Lakes after its introduction. The Great Lakes food web is shown in Figure 1. Learning about the food web occurred in a series of three lessons, as shown in Table 5. In lesson 8, students used the model to make predictions about the effects of the sea lamprey on the other species living in the Great Lakes. In lesson 9, students used a computer simulation (NetLOGO) to understand how food web interactions could be translated into fluctuations in population levels. In lesson 10, students were given actual data of the sea lamprey, trout, whitefish, and chub populations and were asked to analyze these data in light of the food web interactions shown in the model in Figure 1.

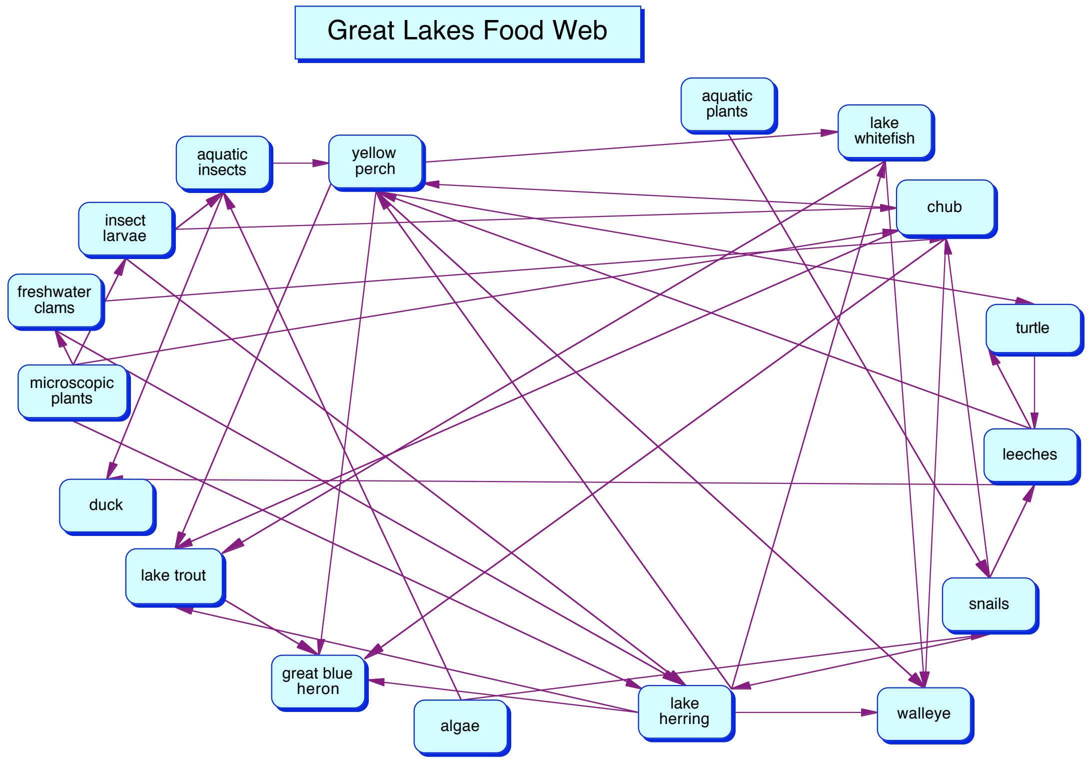


Figure 1. Great Lakes food web presented to students showing the relationships between aquatic and non-aquatic species in the Great Lakes before the introduction of the sea lamprey

The "model" in this case is the Great Lakes food web. I call it a model for several reasons. First, it is an abstraction of naturally occurring relationships in nature that is based on empirical evidence. Second, the food web can be used to explain data such as population fluctuations in species represented in the web. Third, the food web can also be manipulated and used to make predictions about events that have not yet occurred. The food web is a commonly used model in science classrooms to illustrate relationships between organisms in an ecosystem. However, it contains complexity that might make it challenging to understand for several reasons. First, it is a static representation of dynamic relationships in nature. As such, it is also a simplification of those relationships. Students are told that if a species' food source(s) runs out, it will die. In reality, species will often find other food sources in order to survive. Students are also told that species in the food web either live or die. In reality, population levels fluctuate depending on various factors such as availability of resources. This complexity is not represented in the food web. Finally, the food web can be used to make predictions about the effects of changing population levels. It can also be used as a basis for understanding real fluctuation levels in populations of these species. As such, it becomes a tool for understanding observations of real phenomena.

Being able to use the food web to make predictions about and analyze the effects of the sea lamprey on the Great Lakes ecosystem is not a trivial task. The food web communicates information that may be hidden to students unfamiliar with this type of representation. For example, students must understand the directionality of the arrows, which tells them which species is a predator and which is the prey. Students must also understand that if there are multiple arrows emerging from a single species, that species is eaten by several other species. For example, in Figure 1, there are multiple arrows pointing to the yellow perch. This indicates all of the species the yellow perch eats. If the yellow perch were to be removed from the food web, it would have effects not only on its food sources but also on its predators. Finally, the food web consists of multiple, interconnected food chains. It is possible to trace food chains through the food web and understand the effect a single species has on other species. Once students understand the food web as a model, they can then use it as a tool to predict the consequences of changes in the food web. The question, however, is *how* Denise and Sherry attempted to support students' understanding of and eventual use of the model as a tool for analyzing the effects of the sea lamprey on the Great Lakes food web. I explore this question in the following sections.

Denise and Sherry: Elaborating making predictions into epistemic practices

As I discussed earlier, inquiry practices are often difficult to describe because they involve several types of complex reasoning. Using the perspective of epistemic practices, I will first describe the ways in which Denise and Sherry elaborated on the inquiry practice of *applying a model* and, in the process, balanced the need for supporting students' needs and moving on to more ambitious parts of an inquiry practice. I will then use my perspective of inquiry as a Discourse to describe their support of one epistemic practice, *making predictions from the model*, in order to explore how Denise and Sherry balanced the demands of the cognitive, social, and linguistic dimensions. In supporting this inquiry practice, there was very little variation between the two teachers in the epistemic practices they used and the order in which they used them. Table 3 describes the epistemic practices both teachers used to support this inquiry practice.

Denise and Sherry both began the lesson with the epistemic practice of *identifying components and relationships in the model* in which they identified important aspects of the model. These would include identifying the variables in the model such as producers and consumers or identifying important structural features of a model, such as directionality of the arrows. The *identifying* practice involved students in fairly simple reasoning about the model without them having to mentally run the model in order to make claims about it. The following is an example of this practice from lesson 8 in Sherry's class, about two minutes into the discussion:

2:00 into the discussion
Sherry: Andy, what is a food web made up of?
Andy: Um, organisms that consume other living organisms.
Sherry: Ok and what would we call that if we have organisms consuming other organisms?
S: Chain.

11 Sherry: Food chain…So we have food chains connected to each other to great a food web right? We talked about consuming, organisms consuming. What's the beginning point of a food chain, all the way on the right?
12 Jen: Producer
13 Sherry: Producer. And then other things consume it.

In this example, Sherry asks students to identify the components of the food web model: a food chain, a producer, and consumer. This *identifying* practice tended to be fairly simple, asking students to name important parts of the model and describe what happened when the model was run, but it allowed teachers to call attention to important aspects of the model and important interactions between variables in the model. Beginning with this epistemic practice makes sense because it seems important for students and teachers to have a common vocabulary with which to identify aspects of the model before conducting more complex reasoning with it. For example, if there is no agreement on what a "food chain" is and how it is connected to other food chains in the food web, it may be difficult to have students predict the effects of changing one part of the chain.

After it was clear that students were correctly mapping the elements of the model to their referents, students and teachers proceeded to the epistemic practice of *making predictions from the model*. This was the main activity in the lesson as stated in the lesson plan. In this practice, the teachers took students through hypothetical situations in which a change would be made to the model. Students were asked to make predictions about what would happen in the model once that change was made. In the following example, Sherry has drawn a food chain on the board that consists of algae, aquatic snails, chub, and lake trout. The food chain looks like this:

algae → snails → chubs → lake trout

In this diagram, the arrows indicate that the lake trout eat the chubs, the chubs eat the snails, and the snails eat the algae. The initial question posed to the students is: what will happen to the snails if the algae population disappeared? The following example is again from lesson 8 in Sherry's class, about six minutes into the discussion:

6:00 into the discussion
52 Sherry: If something happens to the aquatic snails and that population goes, what's going to happen to the algae?
53 Student: They'll grow
54 Sherry: Why?
55 Lucas: Because there's less things that will eat it.
56 Sherry: Ok so the population grows. What's going to happen to the chub? Alan?
57 Alan: It will die.
58 Sherry: Why?
59 Alan: Without the aquatic snails it will die out unless it has another organism it can eat.

This practice involved students in reasoning about long-term effects of changes in a model given what they know about the current state of the environment. In the example above, Sherry introduces a change to the system: the snails dying out. In order to engage in the practice of making predictions from the food web, students must mentally "run" the model and, based on the interactions represented in the food web, make predictions about the effects on the algae and chub populations. In this case, this involves understanding what happens when a species' food source is removed (as in the case of the chub) and what happens when a species' consumer is removed (as in the case of the algae). The following example is from the same point in lesson 8 in Denise's class, about three minutes into the discussion:

3:15 into the discussion
32 Denise: Ok…What happens then if the snails die and that's the chub's only source of food, what happens to the chub?
33 Eddy: they'll die too.
34 Denise: Ok they'll die too. What happens to the lake trout then?
35 Mario: They might decrease.
36 Denise: They might decrease. Will they die out completely maybe?

37 Mario: They might.
38 Denise: Do they have other food choices? Who was a trout yesterday?
39 Larry: Me
40 Denise: Did you have other food choices besides the chubs? What were you? Do you remember?
41 Larry: I just remember I ate Jose and Corey.
42 Denise: Ok Jose what were you?
43 Jose: Yellow perch
44 Larry: Oh, herring.
45 Denise: Ok the other food choices for the trout are herring and perch. Ok so what happens to the herring?
46 Students: It decreases
47 Denise: Why?
48 Eric: Because more lake trout.
49 Denise: Ok.

In the first part of this example from Denise’s class, in lines 32-39 she is supporting making predictions about the chub and lake trout populations if the snail population dies. However, she decides to introduce a nuance in the predictions in line 40 when she asks “do they [lake trout] have other food choices?”. In this way, she points out that species with multiple food sources might survive if one of their food sources dies out. However, in order to have students make another prediction about the lake trout, she returns to the *identifying* practice to remind students of the relationships in the food web. In lines 41-46, she and the students establish that the trout had other food sources besides the chub and then she returns in line 46 to *making predictions*.

Both teachers alternated between the practices of *making predictions* and *identifying relationships*. While making predictions, the teachers asked students to mentally run the model and predict effects of change in the model. However, whenever the students needed reminding of the relationships between organisms in the model, teachers would return briefly to *identifying relationships*. As in Denise’s example above, the teachers would then return to making predictions based on the relationships they identified.

Towards the end of each activity, teachers enacted the epistemic practice of *constructing generalizations from the model*. This practice involved synthesizing students' predictions in order to construct generalizations about effects of any change in the food web. The goal of this practice was to construct generalizations that would apply to food webs in any ecosystem. In the lesson plan, teachers were to ask students to make predictions about the removal of specific organisms from the food web. However, the lesson plan never explicitly stated for teachers to push for large generalizations about effects of changes in food webs. In my analysis of Denise and Sherry's enactment of this lesson, they inserted the *constructing generalizations* practice in order to synthesize the results of students' predictions and bring closure and purpose to the lesson. The following example is from Denise as she tries to support this practice:

5:50 into the discussion

81 Denise: So what happens if only one food chain is affected? Does it affect the whole system?
82 Students: Mm hm
83 Denise: Ok so…if I pretended I was a lamprey and I came into that food system, what would happen? And I attack the perch first?
84 Mark: We would have all moved
85 T: You would have all what?
86 Mark: Moved.
87 Denise: Moved? If I attack the perch and then the rest of the fish, what happens to the rest of that food system? And this is actually what happened, so…what happens?
88 Eddy: It decreases.
89 Denise: What decreases?
90 Eddy: all
91 Denise: Everything kind of starts decreasing.

In this example, Denise attempts to elicit a generalization from students about what happens to the entire food web when one part is affected. She also relates this activity back to the driving context of the curriculum: to understand the effects of an invasive species on an ecosystem. In line 83 she asks the question "if I pretended I was a lamprey and I came into that food system, what would happen? And I attack the perch first?". In lines 87-91 she attempts to elicit a generalization from students about the effect of adding the sea lamprey on the ecosystem.

This practice of constructing generalizations is complex. In order to construct a generalization, students need to synthesize the outcomes of previous epistemic practices. For example, in the food web activity, students made various changes to the model and mentally ran it in order to track survival and death of certain populations in the food web. They saw that when changes are made to the food web, some populations will survive and some will die. One generalization students could draw from their experience with the model is that survival of a population depends on whether that population's food source or predator was affected. Another generalization students could draw is that everything is eventually affected if one change is made in the food web—a point that Denise tried to draw out of the discussion shown above.

Having formed a generalization, the teachers either tested students' understanding of this generalization by continuing with the identification and prediction practices again with the same model or apply the generalization to a new situation. I called this practice *using the model in a new context*, and its goal was to apply the form of the food web to a new situation. Only Denise enacted this part of the activity even though it was in the lesson plan. In the following example, Denise asks students to apply what they learned about food web interactions to another type of environment with different organisms:

20:55 into the discussion (lesson 8)

222 Denise: Ok…Now let's see if you really understand this…Make a food web using specific insects here, um, specific things. So it talks about terrestrial. What does that mean? Anybody?

223 Larry: Um, something that has to do with the earth.

224 Denise: Something that has to do with the earth. So we're talking about land animals here. Or things that are on the land. So, Conner. What did you start out with? Tell me what you started out with.

225 Conner: Bears

226 T: Bears. And was that in this list? And where did the bears go to?
227 S: Fish
228 T: Ok so they went to the fish. And where did that go to?
229 S; I don't know what fish ate.
230 T: You didn't know what the fish ate. Well actually in your own mind you know that the fish ate right?
231 S: Other fish
232 T: Other fish? Ok. And eventually what could they eat that would be at the bottom of this maybe?
233 S: algae
234 T: Algae. Ok.
235 S: Fish could eat frogs too
236 T: And fish could also eat frogs. You're right about that so maybe we put a frog there, that would be alright.

In this example, students were to construct a food web based on known interactions between organisms such as grass, bears, deer, elk, birds, and lynx. They were to apply what they learned from the Great Lakes food web to the construction and manipulation of this new food web model. During this practice of *using the model in a new context*, students in Denise's class applied the form, or the model, to a new ecosystem and thereby generated a new data set based on the new situation. They then returned to the *identifying/making predictions* epistemic practices and applied them to the new situation. In this series of practices, the purpose seemed to be to strengthen students' understanding of the generalizations they constructed by taking them through the same reasoning steps from the first round of the *applying a model* practice. For example, after discussing the new food web with the students, Denise asks:

27:14 into the discussion
283 Denise: And then again here's the grass. So if I take something out of here what happens, you guys all know, right?
284 Students: everything is affected.
285 Denise: Everything's affected. Either it increases or decreases based on what I've taken out of here. Ok.

In the above example, Denise applies the principles from the Great Lakes food web model to the new instance of the terrestrial food web model introduced in line 222 above. Students at this point seem to understand that everything in the food web can be affected by one small change in the food web.

Summary and Discussion

Denise and Sherry's attempts to support the *applying a model* practice illustrate one pedagogical approach to operationalizing inquiry practices in classrooms. It is useful here to compare the teachers' enactments with the instructions in the curriculum materials in order to better understand the teachers' support. Both teachers' enactments of this inquiry practice differed from the written curriculum in similar ways. For example, the curriculum states that at the beginning of this discussion,

1. Remind students that they had created the Great Lakes food web in yesterday's activity. Ask students: What did we mean by the term food web? What did our food web illustrate? *Answer: A food web is composed of many interconnected food chains.*
2. Have students recall what happened to the food web when they took out a population of an organism. Students should say that the food web fell apart and that different food chains were affected by this organism's absence.[3]

Therefore, teachers were asked to remind students of what a food web is, what it is composed of, and what happened the previous day when they took out an organism in the food web. What I saw the teachers doing in the *identifying* epistemic practice therefore represented an elaboration of the curriculum materials in that I saw both teachers going into more detail in their review of the food webs. The lesson then asks teachers to make predictions with students:

5. Have the following food chain up on the board prior to class.

   Algae ---- aquatic snails ---- chubbs ---- lake trout

[3] The complete lesson plan can be found in Appendix A.

Ask the students: Predict what would happen to each of the organisms if the snails were removed from this food chain? (Remind them we are talking in terms of populations of organisms and not individuals.)

Answer: Algae population in this food chain would increase because nothing would be eating it and the chubbs population would decrease do to one of their food sources being gone. That would cause an indirect decrease of lake trout.

6. Put the overhead of the Great Lakes food web up on the overhead projector. And ask the students: If the snails are removed are there any other organism it would be affected?

Notice that the curriculum materials state the instructions to the teachers very simply: "Predict what would happen to each of the organisms if the snails were removed from this food chain". What I saw the teachers doing went beyond this when they asked for reasoning, introduced nuances into students' predictions, and returned to the *identification* practice as they were making predictions.

The curriculum materials did not support teachers in the *constructing generalizations* practice. At the end of the lesson, teachers were to ask students about the effects of adding an organism to the food web and how changes in the aquatic food web would affect the terrestrial food web:

13. We've been talking about removing different organisms from the environment, what if something was added instead of removed? If a new organism invaded the environment and held the same position in the food web as a native organism, have students consider all the possibilities of what might happen. *Answer: There would be a competition between the invasive (added) species and the native species.*

14. Ask the students: Do you think that the changes that occur in the Great Lakes food web would affect the organisms that live on the land? *Answer: Yes, because the terrestrial food web is connected to the aquatic food web. Some of the birds and other animals feed on the aquatic plants and fish also live on land and are prey for organisms that live there.*

The curriculum materials therefore stop short of asking students to form generalizations from their work with the food web model. Therefore, by *constructing generalizations*, both teachers went beyond the curriculum materials as they concluded this lesson. The teachers' enactments of this practice therefore signal a site where there could have been more support for teachers and students to bring closure to the lesson. Finally, the practice of *using the model in a new context*—a practice that only Denise enacted—was in a homework assignment for the students. This was probably why we did not see Sherry engaging students in this practice.

Figure 2 summarizes the system of practices the teachers used for this purpose. As Figure 2 shows, the teachers alternated between *identifying* and *making prediction* practices and then moved to *constructing generalizations*. At this point, they would either return back to *identifying* and *making predictions* or move to *using the model in a new context*. Only Denise enacted this practice. She then returned to the to *identifying* and *making predictions* level of the system to test students' understanding of the model in the new situation by making predictions. Therefore, the inquiry practice of *applying a model* actually consisted of at least three epistemic practices as show in Figure 2, with Denise adding the *using the model* practice.

The task in the curriculum was to understand the food web model, be able to predict consequences of changes in that model, and apply the model to a new situation. As I discussed above, this was a complex task because the model itself contained complex information that students needed to learn how to decode. I argue that this process of breaking the inquiry practice into epistemic practices represents one way the teachers attempted to make the inquiry practice more accessible to students. Each epistemic practice seemed to build on another so that students' participation in the more complex parts of the task such as constructing generalizations was scaffolded by participating in the simpler reasoning tasks such as identification and making predictions. For example, in order to make generalizations from a model, students need to participate in many rounds of predictions in order to generalize from those predictions. In order to make predictions from a model, students need to first understand what the important parts of the model are, which they do through the *identifying* practice.

My analysis of epistemic practices began as a way to specify the steps teachers were taking students through as they attempted to support them in inquiry practices. I was searching for a more precise language to describe these steps and epistemic practices afforded that language. However, my analysis also resulted in furthering our understanding of one aspect of teachers' support of students' participation in inquiry practices. By studying the progression of epistemic practices within the system as shown in Figure 2, we can see one way teachers may be able to operationalize an inquiry practice in classrooms. By taking students through a progression of reasoning steps, teachers may be able to see for themselves where students need extra support and where they can be allowed more freedom to explore their own ideas.

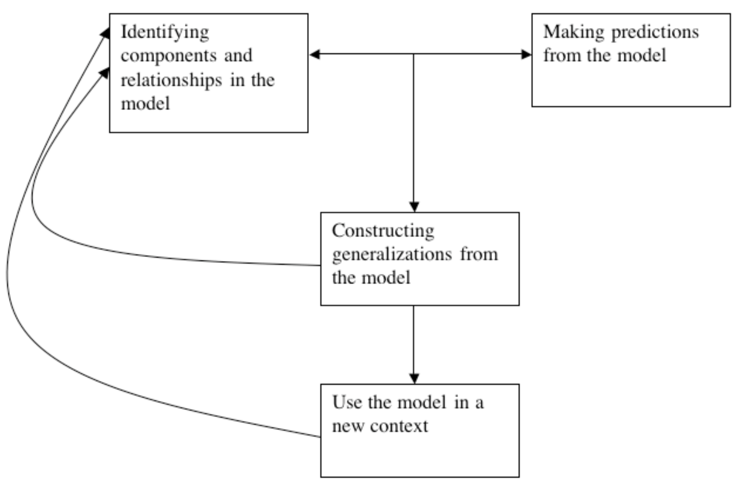


Figure 2: System of epistemic practices for *applying a model*.

The perspective of epistemic practices also affords a way to explain the types of demands teachers balance as they support inquiry practices. For example, the curriculum asked teachers to take students through making predictions from the model, but it never explicitly asked them to help students construct generalizations from those predictions. However, both teachers seemed to recognize the need for this in order to bring some resolution to the activity. Perhaps because it was not explicitly supported in the curriculum, Denise and Sherry each spent very little time on this practice. This is interesting given how challenging it may be to form a generalization by synthesizing the results of multiple rounds of making predictions. This points to a pedagogical challenge in supporting students in inquiry practices: teachers need to provide enough support at the front end of a practice (in this case, the *identifying* and *making predictions* epistemic practices) so that students gain enough experience with those reasoning steps. However, the more challenging and ambitious parts of the practice themselves need support and are the more desirable outcomes in terms of students' reasoning with the content. In this case, the curriculum materials did not do a good job supporting teachers (or students) in these more ambitious practices, so it was no surprise that teachers did not focus on the *constructing generalizations* or *applying the model to a new context* practices.

Inquiry practices are often difficult to characterize because they involve multiple reasoning steps. By using the perspective of epistemic practices, I was able to understand the ways in which Denise and Sherry interpreted the important reasoning tasks involved in the inquiry practice of *applying a model.* The system of epistemic practices shown in Figure 2 is part of the support the teachers used for this inquiry practice. However, each epistemic practice shown in Figure 2 is itself a site where further support may be needed. In the next section, I will unpack one epistemic practice, *making predictions from the model*, in order to understand the dimensions around which teachers provided support.

Teachers' support of making predictions from the model

In this section I will describe how my perspective of inquiry as a Discourse can help characterize the multiple demands in each dimension that teachers need to balance. I will take one epistemic practice that I saw the teachers using, *making predictions from a model,* to explore this issue. Making predictions based on preliminary evidence is an important scientific practice. It guides the collection and analysis of data during an investigation. In this activity, students were given the food web model and were asked to use that model as a basis for making predictions. The end goal in this series of lessons was for students to use the food web model to understand actual data of population fluctuations in certain species in the Great Lakes. Before doing this, however, students needed to practice using the food web model as a tool for making predictions. In order to understand the nature of Denise and Sherry's attempts to support this epistemic practice, I ask the following questions: *Do teachers provide support along multiple dimensions as they enact inquiry practices? Which dimensions do teachers emphasize and when are they emphasized? How and when do teachers communicate the norms for reasoning, interacting, and using language that inquiry practices entail?* I will answer these questions by first analyzing Denise and Sherry's enactment of *making predictions from a model* and then discussing my findings in light of my perspective of inquiry as a Discourse.

Denise: structured support for making predictions

Denise's enactment of *making predictions* is an example of a teacher using very structured interactions to achieve ambitious types of thinking such as making predictions from a model. I found that Denise's support for making predictions could, indeed, be characterized in terms of multiple dimensions. However, she was seldom explicit in her support of this practice except when she was introducing linguistic terms that may have been unfamiliar to her students. In the excerpt below, Denise asks the students to predict what will happen to the lake trout when the sea lamprey is introduced into the Great Lakes food web.

10:27 into discussion (lesson 10)

99 T: Ok. So if I said lake trout, what are you guys going to tell me might happen? Here's the sea lamprey [points to the food web on overhead], here's the lake trout. What's your prediction—up, down, or stay the same?
100 Larry: Down
101 T: And what's the evidence, what are you basing it on, what knowledge do you have when you're making that prediction…Eric what did you want to say?
102 Eric: Because it's one of their favorite food.
103 T: Because it's their favorite food. Ok. So in lake trout, what would you write? What will you write in the lake trout square?
104 Larry: It went down
105 T: Went down. Based on?
106 Eddy: Sea lamprey ate them
107 T: Ok. Eric what did you say? Sea lamprey's favorite food.
108 T: Favorite food. Ok. Nice job.

In this example, Denise is using two strategies to support students' cognitive reasoning in this task. The first is what I call *probing for evidence*. In lines 101 and 105 after Larry makes his claim, Denise asks him to provide evidence. In asking for evidence, she explains what evidence means by restating the definition of "evidence" in a couple of different ways: "what are you basing it on", "what knowledge do you have when you're making that prediction". By doing this, she communicates the cognitive "rule" that predictions in this context include both a claim and evidence—a rule that may not be apparent to students who are unfamiliar with making scientific predictions.

The second strategy Denise uses is *structuring the discussion* around specific content—the food web—in order to communicate the rule that predictions need to be based in the food web. This strategy involves signaling to students where they should be drawing their evidence or reasoning. At the beginning of this excerpt, Denise points to the food web model in line 99 before asking for students' predictions. This emphasizes the importance of basing predictions in the food web model and signals to students that the food web is an important data source from which to make predictions. When students are presented with many sources of data, it may be important for teachers to help students understand which pieces of data are most relevant for answering particular questions.

These cognitive supports for *making predictions* signal to students the types of reasoning that this practice entails: students not only need to make predictions, but their predictions need to be supported with evidence. The evidence they use needs to be based in the food web model. Denise's use of probing and structuring are subtle cues to the students as to the types of reasoning they need to do in this practice.

Related to the cognitive supports she provides, Denise provides very concrete linguistic support for what the scientific terms "prediction" and "evidence" mean in this context. In line 99, Denise uses the term "prediction" and defines it as "up, down, or stay the same". She scaffolds the use of the scientific term "prediction" by providing the only three appropriate options that students can provide for their predictions. She uses a similar strategy in line 101 when she says "what's the evidence, what are you basing it on, what knowledge do you have when you're making that prediction". She uses the term "evidence" and then defines it in the same sentence. In this case, Denise's linguistic support of the terms "evidence" and "prediction", both of which have very specific meanings in science, is closely related to her cognitive support of what it means to make a prediction in this context. In order for students to make a prediction from the model, they first need to understand what "prediction" means. If making a prediction means backing up a claim with evidence, students also need to understand what "evidence" means.

Denise provides, almost simultaneously, support in both the cognitive and linguistic dimensions as she engages students in the practice of *making predictions from a model*.

Finally, Denise uses a series of strategies to communicate to students what their role is in this discussion. I characterize these as support in the social dimension. She begins by restating Eric's exact words in line 103 and again in line 107: "sea lamprey's favorite food". In this way, she validates Eric's contribution to the discussion and signals to students that their role in this practice is to co-construct the predictions with her. Starting in line 103, Denise then synthesizes students' ideas so that the final prediction, which the class writes down on their worksheets, is a combination of students' contributions. In this series of teacher moves, Denise is attempting to draw students into the discussion by validating their participation and co-constructing important ideas with them. This support in the social dimension is important to give since inquiry practices often involve students in engaging with ideas in more active ways—by participating in discussions, by critiquing each others' ideas, by looking for alternative hypotheses. Although students do not take on these types of roles in the discussion above, Denise is tacitly communicating to students that she expects them to take an active role in discussions and in the co-construction of important scientific ideas.

Although I only showed a short segment of dialogue from Denise's lesson, my framework of inquiry as a Discourse can afford interesting descriptions of the aspects of inquiry the teachers emphasized. This analysis allows me some insight into the nature of Denise's attempt to support the epistemic practice of *making predictions*. First, her enactment of this practice can be characterized in terms of cognitive, social, and linguistic dimensions. In other words, she uses various strategies such as probing for evidence and scaffolding to communicate rules of this practice within each dimension. These rules are summarized in Table 5.

Furthermore, with the exception of her support at the linguistic dimension, the strategies Denise uses are very subtle and never explicitly stated. Finally, she moves from one dimension to another fluidly and without transition. Therefore, although Denise is providing support within all three dimensions, it is up to the students to pick up on her cues and follow suit.

This analysis also highlights the ways in which a teacher might engage students in complex reasoning within very structured interactions. Denise's pattern of talk resembles traditional IRE sequences in which a teacher asks a question, a student responds, and the teacher evaluates the student's response. She asks known-answer questions and occasionally, as in line 122 above, fill-in-the-blank questions. However, the questions she asks require students to make predictions from the model and provide evidence for those predictions. The result is that she gives students the opportunity to engage in the practice of making predictions at the same time that she communicates the important rules for this practice. The downside of these structured interactions, however, is that she gives students fewer opportunities to engage with each other or struggle with defining scientific terms and inquiry processes for themselves.

From interview data with Denise, we learn that she believed that the most challenging aspect of inquiry for her students would be overcoming linguistic challenges that arise in science. This concern was based on the makeup of the population of her students, which consisted of over 95% second language learners. She was concerned that her students would have a more difficult time engaging in inquiry processes because they did not understand the language of science. Denise provides very concrete support in the linguistic dimension. She balances the need to provide linguistic support with the need to push students to accomplish ambitious goals in inquiry. This results in interactions that are very teacher-directed but also quite ambitious.

However, this emphasis on the linguistic dimension may come at a cost: it leaves less time for students to take a more authoritative role in the classroom.

However, compared to the ideal inquiry components I listed in the Introduction, Denise seems to fall short. While she seems to be helping students provide evidence for their predictions, she does so in a way that allows them very little freedom to explore their own ideas. Because of the very structured way in which she asks questions, she does not seem to give students the opportunity to communicate their ideas in a thoughtful and articulate way. However, my multidimensional framework helped to see how, within one epistemic practice, a teacher may need to lay the conceptual groundwork before accomplishing any ideal inquiry component. In this case, Denise needed to communicate the rules for using evidence to support a prediction but also communicate what "evidence" meant in this particular context. Finally, she needed to encourage students to engage in this practice in an active way, signaling a change in the way they participated in "school science" before this unit. Because of her perception of the needs of her students, however, her support took a very structured form, leaving the students with little freedom to explore ideas on her own. We might therefore think of Denise's case as one in which she may realize what the ideal inquiry practice may be, but she is balancing those demands with her perceived needs of her students.

TABLE 9. Summary of cognitive, social, and linguistic rules in Denise's enactment of making predictions.

Dimension	Rule	Strategy
Cognitive	• Predictions include claim and evidence • Evidence is based in the food web	• Probing for evidence • Structuring around content
Social	• Students' role is to co-construct predictions with teacher	• Probing to expand • Repeating students' exact words
Linguistic	• "Prediction" means up, down, or stay the same • "Evidence" means what are you are basing your prediction on, your knowledge	• Scaffolding the use of scientific terms

Sherry: Subtle support for making predictions from a model

Sherry's enactment of *making predictions* is an example of a teacher using extremely subtle cues to support students in this practice. Although she is almost never explicit in her support, she is able to elicit the types of responses from her students that we, as designers of the curriculum, would consider to be showing successful engagement in this practice. As in Denise's case, she provides support along all three dimensions, but in a more subtle way than Denise. In the following excerpt, she is asking the students to predict what will happen to the chub population when the sea lamprey is introduced into the food web.

8:18 into the discussion (lesson 10)

26 T: Ok. What about the chubs? What do you think is going to happen? Sir?
27 Frank: The population will still be balanced.
28 T: The population will be balanced. Why? What do you think?
29 Frank: From the food web, that one of the chubs' predators is the lake trout but because the lake trout is decreasing, there would be more chubs even though there's the lamprey will balance out the ones that are increasing.
30 T: Ok so you say it's not going to be different, they're going to balance out because while you lose the predator of the lake trout, we gain the predator of the sea lamprey. Ok. Anybody else have something?… Mary what did you have?
31 Mary: They would stay the same.
32 T: You said it would stay the same why?
33 Mary: Because the chub has one less predator because the lake trout is being eaten and it also has the sea lamprey eating it.

34 …
35 T: Anybody else have anything? Jen what did you guys have?
36 Jen: We put decrease
37 T: Why?
38 Jen: Because the chub has other predators besides the lake trout and the sea lamprey so it's kind of getting the double whammy too with its other predators and the sea lamprey. And since the sea lamprey's um an invasive species, there's more eating the chub..
39 …
40 T: Um anybody have that chub will go up? Why Steve?
41 Steve: I said because um, the sea lamprey is going to eat more of the lake trout because it's the biggest fish, and so it will have more time to reproduce.
42 T: Ok. Anybody else?
43 Annie: We put that the population will first go up and then it will go down.
44 T: Why?
45 Annie: Because it also has whitefish as the predator…and then it will go down when the sea lamprey eats it
46 T: Ok so it will go up because it loses its predator the lake trout. The assumption is that the sea lamprey is eating all the trout and not paying attention to the chub, right?
47 Ss: Yeah
48 T: And then when the trout is gone it will all go after the chub. Ok, anybody have anything else you want to add about chub?

In this example, the students and Sherry seem to be operating under several shared assumptions that are communicated in very subtle ways. For example, Sherry uses the same strategy as Denise to communicate cognitive rules of this practice. She probes each student for evidence after they state their claim in order to signal the importance of backing up claims with evidence. Furthermore, students seem to understand that having reasons for their predictions are important parts of this practice. In line 29, Frank shares the reason for his prediction after Sherry asks "why", which seems to be a sufficient prompt to elicit a pretty sophisticated response. Indeed, immediately following Frank's answer, Sherry re-states his response and moves to another student, thus signaling that Frank's answer was acceptable. In the rest of this discussion, students seem to share the understanding of this linguistic marker. For example, in line 38 Jen says

> the chub has other predators besides the lake trout and the sea lamprey so it's kind of getting the double whammy too with its other predators and the sea lamprey. And since the sea lamprey's um an invasive species, there's more eating the chub.

Her evidence is that the chub has other predators besides the lake trout and the sea lamprey and her reasoning is that there are more predators eating the chub. Sherry's use of the prompt "why" to elicit such sophisticated answers from her students suggests that this was a norm that was already established before our curriculum was enacted in this class. Nevertheless, it was useful for signaling to students the next step in the practice, which was to provide a reason for their prediction. Sherry's consistent use of "why", as seen in this example, serves to illustrate to students this importance of providing reasoning to the practice of making predictions.

Finally, Sherry communicates the cognitive rule that there are multiple acceptable responses to the same phenomena when making predictions. She does this by probing for multiple responses in lines 32, 37, 42, and 44. In a traditional classroom, her asking for another response may be a signal that the first response was incorrect or somehow inadequate. However, Sherry provides no such judgment as she moves from student to student asking for their responses.

By combining several strategies—probing for evidence, probing for multiple responses, using linguistic cues—Sherry provides very subtle support for students in the cognitive dimension of this practice. Furthermore, as in Denise's case, the linguistic and cognitive supports are very closely linked. The linguistic marker "why" in this context had specific meaning that students seemed to share with the teacher. It signaled a specific type of response and, therefore, certain rules about this practice of making predictions. Notice that Sherry never said "making a prediction means backing up claims with evidence and reasoning", and yet through her cues she was able to elicit types of ambitious responses the curriculum strived for. Students, whether they were aware of it or not, made a prediction, backed it up with evidence, and provided reasoning. This, according to the curriculum, was considered a successful way to engage in this practice. Support in the linguistic dimension in this case served to reinforce the cognitive elements of the practice of making predictions.

Sherry also asks several students for their predictions. In fact, she keeps asking for students' responses until almost every group of students has shared their responses. In this way, she indicates the social roles students are to play in this discussion. For the epistemic practice of making predictions, it is not enough to have simply formulated a prediction. Students' role in this context is to share their predictions with the class. Sherry communicates this rule by asking almost every group what their predictions were. In traditional science teaching, one could imagine students filling out a worksheet and turning in their predictions to the teacher, or only one student sharing their response and the teacher moving on. In this case, Sherry clearly communicates that the students' role in the discussion is to share their predictions.

Summary and Discussion

As I described in Denise's case, Sherry attended to all three dimensions in her attempt to support students in this epistemic practice. Using the multidimensional framework, I illustrated how Sherry seemed to emphasize the social dimension, hearing all students' ideas without passing judgement on any of them. She used very subtle cues to communicate aspects of each dimension and yet she somehow succeeded in getting students to engage in the full practice of making predictions and supporting those predictions from evidence. Again, however, Sherry seems to fall short of the "ideal" inquiry components I listed in the introduction. Although she engages the students in communicating their ideas, she does not foster the discussion so that they are actively engaging with each others' ideas. By moving so quickly from group to group, one gets the sense that she is conducting a survey rather than a critical discussion of ideas. However, my analytical framework again allows some insight into what work Sherry is doing. As I said before, she is actively engaging students in the process of constructing predictions based on evidence and communicating those predictions to the class. She uses linguistic cues to signal next steps in reasoning that students should engage in. Finally, she sets up expectations in the social dimension for how students need to engage in the public part of the practice.

This case raises a number of interesting issues about supporting students in inquiry. My analysis highlights the multiple demands placed on teachers when supporting inquiry practices. In the above example and throughout her enactment of this unit, Sherry places a strong emphasis on the social roles students play. Sherry places herself not as the sole authority in the class but as a facilitator of students' ideas. She makes sure all students' ideas are heard which results in may students being able to actively participate in discussions, but in this way spends less time giving concrete support in the other two dimensions. For example, the time Sherry devotes to students sharing their ideas seemed to take away from coming to consensus around the strongest predictions and reasoning. Sherry's communication of rules at the three dimensions is very subtle, which may lead to confusion on the students' part about, for example, the meaning of scientific terms.

Furthermore, because classroom time is a limited resource, having all students share their predictions takes away time for consensus-building and synthesizing of information, two teaching practices I saw relatively little of in Sherry's enactment of this curriculum. There is a tension in treating multiple dimensions at the same time. As I illustrated in Denise's case, emphasizing one dimension can take away support of the other dimensions. In Sherry's case, she seemed to assume a set of shared norms of interaction among her students, but what happens when these norms are not shared or understood by all students? Although I found evidence of support in all three dimensions in Sherry's enactment of this practice, the support was subtle and depended on this shared understanding. Learning elements of this and other inquiry practices may be made more difficult if the support remains on a tacit level and is never stated explicitly.

TABLE 10. Summary of cognitive, social, and linguistic rules in Sherry's enactment of making predictions.

Dimension	Rule	Strategy
Cognitive	• Predictions include claim and a reason • Multiple predictions are acceptable for the same phenomenon	• Probing with a "why" question after a student makes a claim • Eliciting multiple responses
Social	• Students' role is to construct *and* share predictions	• Eliciting *all* students' responses
Linguistic	• "Why" means backing up claims with evidence and reasoning	• Revoicing students' responses

My analysis of Denise and Sherry's enactment of *making predictions* suggests some interesting issues regarding the support of students in inquiry. First, we found evidence of the teachers attending to cognitive, social, and linguistic dimensions, suggesting the importance of these elements to the practices. This analysis was able to articulate some of the specific demands for each dimension. For example, in the cognitive dimension, one demand on teachers is to somehow communicate what the next steps in reasoning are such as providing evidence for a claim. In the linguistic dimension, one demand may be to provide definitions for scientific terms that students are not familiar with. This also helps explain why teaching tensions might occur as teachers enact inquiry curricula. If a teacher emphasizes aspects in the social dimension such as making sure to hear all students' answers, this may take away class time and effort that could be devoted to understanding aspects in the other dimensions.

Another issue that arises as a result of this analysis is that support of one dimension often occurred simultaneous with support of another dimension, as was the case with the cognitive and linguistic dimensions. This suggests the interrelatedness of these dimensions within an inquiry practice. Specifically, teachers may use the linguistic dimension as a tool for making the cognitive and social dimensions more explicit. Finally, support of each dimension seemed largely tacit with the exception of Denise's linguistic support. Neither teacher explicitly explained the nature of the practice. Instead, they used various strategies to communicate rules of the practice within each dimension. This suggests a major challenge in the design, instruction, and learning of inquiry practices: what does it mean to be explicit about a practice? If rules of practices are communicated tacitly, how and when do students learn them? My analysis suggests that teachers may build on classroom norms of interactions, subtle cues, and various scaffolding strategies to communicate these rules. Further research needs to be done as to the effectiveness of these strategies in helping students understand how to engage in inquiry practices.

Teachers' support of data interpretation

Data interpretation is a complex practice that is often found in inquiry investigations. Although students may not collect their own data, they may interpret data collected by others and form scientific conclusions based on scientific principles and patterns in the data. This is not a trivial task. In order to interpret data such as those found in Figures 3 and 4, students must first understand the mechanics of the graph: the meaning of the axes, how to use the title and the legend. They must then understand the trends in the graphs based on their understanding of scientific principles such as food web interactions. In this case, students must understand the food web relationships shown in Figure 5. Furthermore, the information on the graph represents the population levels of each species even though the graphs represent the number of fish caught. Students also need to map the trends in the data in Figure 3 to the trends in the data in Figure 4: as the number of sea lamprey caught increases, this has ramifications on the populations of trout, chub, and whitefish. Whether or not the population of these fish increases or decreases depends on the food web relationships depicted in Figure 5.

The last lesson in the sea lamprey investigation involved students analyzing the data in Figures 3 and 4 to draw conclusions about the effects of the sea lamprey on the trout, whitefish, and chub populations. This lesson follows the food web lesson described in the previous sections. Students needed to use their understanding of the food web relationships between the sea lamprey, trout, whitefish, and chub to interpret the trends in the data. Based on these interpretations, they were to draw conclusions about the effects of the sea lamprey on the trout, whitefish, and chub in the Great Lakes over a time period of 1940-1970.

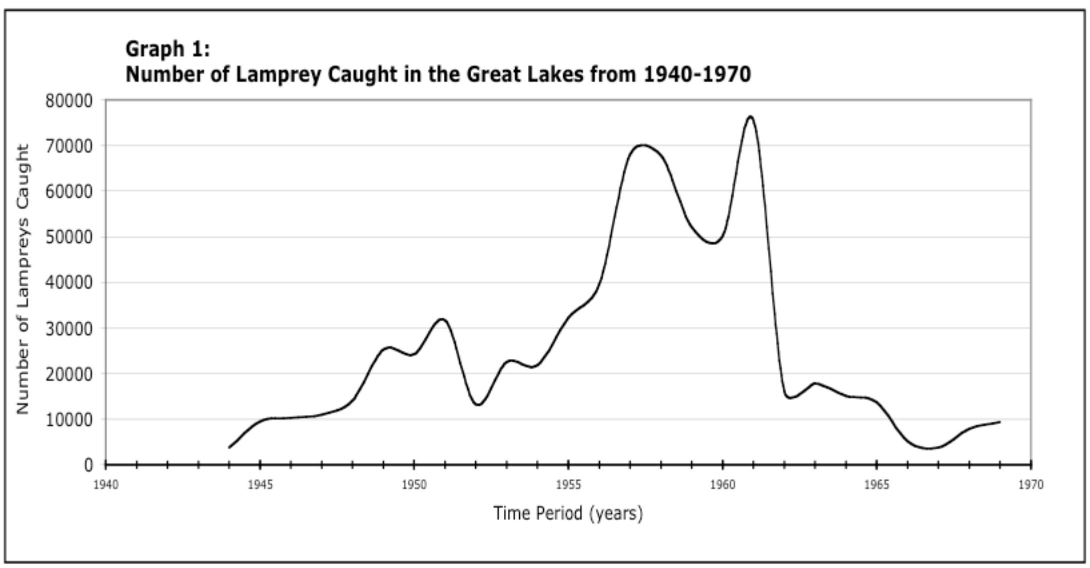


Figure 3. Graph showing the number of lamprey caught in the Great Lakes between 1940 and 1970.

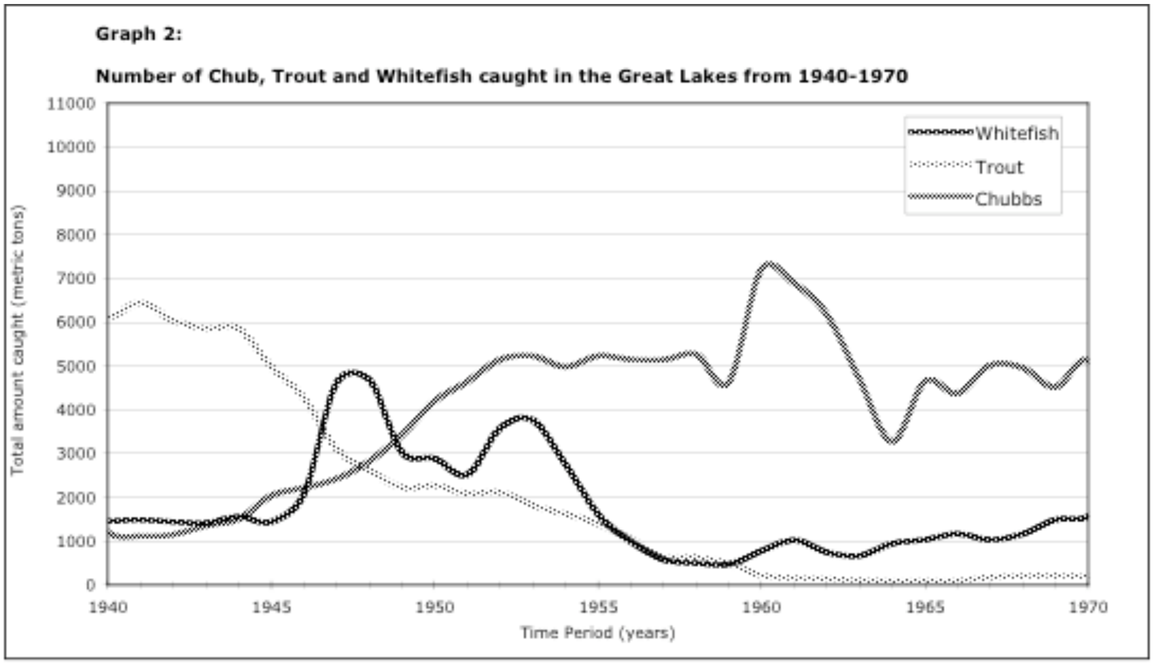


Figure 4. Graph showing the number of chub, trout, and whitefish caught in the Great Lakes from 1940 to 1970.

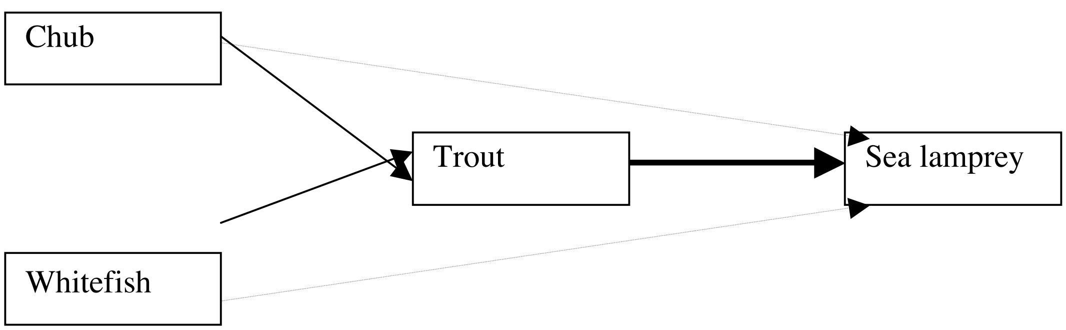


Figure 5: Food web relationships that were the focus in the data interpretation lesson. In this diagram, the chub and the whitefish and eaten by the trout. The sea lamprey's main food source is the trout, but if the trout population gets low enough, the sea lamprey will then prey on the chub and the whitefish.

Teachers' support of data analysis

As we saw with the *applying a model* practice, Denise and Sherry used similar epistemic practices to elaborate on the inquiry practice of *data analysis*. In this lesson, students were asked to divide the graphs in Figures 3 and 4 into four time periods. They were then asked to determine whether the graphs were *stable, unstable, increasing,* or *decreasing* within that time period. After determining the direction of the trend in the graphs, students were then asked to form explanations for these trends based on the food web relationships shown in Figure 5.

Denise and Sherry both used the same three epistemic practices to support this inquiry practice. The epistemic practices the teachers used and a description of those practices are shown in Table 11.

TABLE 11. Epistemic practices Denise and Sherry used to support the inquiry practice of *data analysis*.

Epistemic practice	**Description of the epistemic practice**
Identifying trends in the data	A practice that focuses on identifying and naming trends in the data
Explaining trends in the data	A practice that focuses on constructing an explanation for the trends in the data
Forming generalizations from the data	A practice that focuses on forming generalizations from the trends in the data.

As with the *applying a model* inquiry practice, both teachers started with a type of *identification* practice: *identifying trends in the data*. The goal of this practice seemed to be to identify the trend and give a name to that trend. Although the goal of the lesson was to explain the trends based on the food web interactions, both teachers spent the bulk of the lesson on *identifying trends*. Students had a difficult time in this lesson applying the terms *stable* and *unstable* to the data shown in Figures 3 and 4. The following example is from Denise's class in which they identified the trends in the data:

34:54 into the class
295 T: Alright let's look at the trout. Between 1910 and 1944, what happens to the trout? [T has graph on overhead]
296 Lin: Stabilized
297 T: Stabilized, equilibrium, whatever, ok? Alright, between 1910 and 44, the trout are stabilized. Between 1944 and 1963, what's happening to the trout?
298 Edison: Decreased
299 T: Tremendous decrease or just a decrease?

300 S: Dramatic
301 T: Major downfall, major downfall, something in that nature. It's not just a decrease, ok? Alright, between these 2 years, 1963-69,
302 S: I put almost very low
303 T: Very low
304 S: No very very low
305 T: Very very low.
306 S: Almost dead
307 T: Almost dead. Ok I like those. Very very low, almost dead, still on the decline, right? Ok between 1969 and 2000, what's going on with them?
308 S: I put stabilized
309 T: They're kind of stabilizing themselves again. So are they on the increase?
310 S: Very little
311 T: Very little increase but they are on the increase, ok?

The goal of *identifying trends* seemed to be to both identify the trends in the graphs and establish a language with which to describe those trends. Even though the terms *stable, unstable, increase,* and *decrease* were given on the worksheet for students to use, the application of these terms to the data was not obvious. Therefore, both teachers spent much of the discussion time helping students describe the trends in the data.

The next epistemic practice the teachers supported was *explaining the trends in the data.* In this lesson, students needed to not only understand the trends within each time period but also the changes in the data over multiple time periods and the reasons for those changes. The practice of *explaining* involved creating a "story" from the data. The following example is from Sherry's class in which they have just finished identifying the trend in the data and are now building a narrative around those data to make sense of what happened:

3:50 into discussion
34 T: Ok. So in this time period, what happens? Annie?
35 Annie: It's an overall decrease
36 T: Overall decrease? Stable or unstable?
37 Annie: Unstable.
38 T: Ok. Why do you think that happened?
39 Annie: Because the sea lamprey started eating them.

40 T: Ok. Anybody disagree with that? Does this coincide with the time when we look at…
41 Ss: Yes
42 S: That's when the sea lamprey…
43 T: [puts up overhead of lamprey data] Whoa. Look.
44 Jen: What is that, lamprey?
45 T: Mm Hm.
46 Jen: So it's going up. It's eating more up there of that—what is that, trout?
47 T: Yeah. This is trout. Now this is not perfectly—now I don't know if it's like this or…[T has trout and lamprey graphs on top of each other on the overhead]
48 S: 1970, that's when it starts like—it took time for it to decrease.

In this example, Sherry attempts to support the *identifying* practice with students in lines 34-37, trying to identify the trend in the data for this time period. She then asks students for a reason for the trend. Sherry then puts up an overhead of the graph in Figure 3 for students to link the population level of the sea lamprey to the population level in the trout. By linking these pieces of information together along with the food web interactions shown in Figure 5, students are able to tell a story that explains the trends in the graphs. When a student says in line 48 "it took time for it to decrease", she is attempting to explain the pattern in the data that shows that the peak in the sea lamprey population came slightly before the decline of the trout population. This practice builds on *identifying* because students are not only labeling the trends in the graphs but they are trying to make sense of those trends by constructing a story or narrative around those trends by linking multiple pieces of information together. Both Denise and Sherry alternated between *identifying* and *explaining* as they progressed through the time periods in the graphs. They first identified the trends in the graphs and then attempted to construct a narrative for those trends within each time period.

The third and final epistemic practice supported in *data analysis* was *constructing generalizations*. This was a practice that only Sherry supported and was not in the written curriculum. This practice involved students forming generalizations about the trends in the graphs. The goal of this practice seemed to be to link this lesson with the overall goal of the curriculum: to understand the effects of an invasive species on any ecosystem. In the following example, Sherry attempts to use students' interpretations of the graphs in Figures 3 and 4 and students' understandings of the food web relationships to form a generalization about the effects of an invasive species on the Great Lakes food web:

30:58 into the discussion
376 T: Once we introduce the lamprey, what happens?
377 [ss all answer at once]
378 T: Instability, right? It's similar to that net LOGO, where we introduce the invasive species and everything gets whacked out of balance, right? And hopefully they're going to stabilize a little bit as we go… So, we put [T puts good web overhead up]—we put the sea lamprey in [T draws in sea lamprey on the food web].
379 T: So, we put [puts food web overhead up]—we put the sea lamprey in [T draws in sea lamprey on the food web]. Sea lamprey eats…what is it, chub and trout. When we introduce this, or when this is introduced in whatever form or fashion, it ends up in our Great Lakes food web, is it affecting our food web?
380 Ss: Yes
381 T: Um, do you think if we ended up with another animal in this food web, would it do a similar thing where it would sort of knock it out of balance?
382 S: Yes
383 Jen: Would it be, ok the sea lamprey would be there and you would add another animal?
384 T: Add anything except for a producer. So let's add a…new kind of turtle that's more efficient at catching fish. If we add any other organism to this, if it's introduced, is it going to affect this food web?
385 Ss: Yes
386 Jackie: I think it depends on the qualities it has. If it has like the sea lamprey
387 T: Ok
388 Jackie: that you know, depends on more big fish
389 T: Ok. What if it depends on little fish? Is it going to affect…
390 Ss: Yeah
391 T: Do you guys remember when we did these chains? Are they affected whatever size they are? Does it affect something?
392 Brittney: Look when you add the sea lamprey it affected a whole lot of stuff. If you were to do another one…
393 T: Ok.
394 Jackie: Yeah it affects one, it affects everybody else.
395 T: Overall everything. And it may not just be the aquatic food web. Is it going to affect the terrestrial?
396 Ss: Probably

397 T: Possibly. It certainly affects us. Right? It affects us whether it's financial or otherwise. Yes ma'am.
398 Jen: So what you're basically saying is that it can affect it directly and indirectly.
399 T: Absolutely.

In this example, Sherry involves the students in forming generalizations based on several preceding lessons in the curriculum. In line 378, Sherry references Net LOGO, a computer simulation students used to understand fluctuating population levels and the effects of an invasive species on those population levels in a food chain. NetLOGO was students' first introduction to stable and unstable populations. Also in line 378, Sherry references the Great Lake food web and the sea lamprey's place in that food web. In order to make sense of the trends in the data, Sherry reminds students of all of the pieces of information they have gathered so far in the unit and how those might be used to understand the sea lamprey's effect on the Great Lakes ecosystem. In line 382 she asks, "do you think if we ended up with another animal in this food web, would it do a similar thing where it would sort of knock it out of balance?" Students then generalize outside of the single example of the sea lamprey to the consequences of *any* addition to the food web.

Although Sherry's interactions with students in this example seems fairly structured and directive, she is asking students to perform very complex reasoning: to transfer what they have learned from the sea lamprey case to another case where the effects may be different. In line 386 Jackie attempts to construct a generalization by saying "I think it depends on the qualities it has. If it has like the sea lamprey that you know, depends on more big fish." Sherry then pushes her to generalize even more broadly when she says, "What if it depends on little fish?" Sherry and the students finally reach a generalization at the end of the excerpt when Jackie says "Yeah it affects one, it affects everybody else."

Data analysis is a complex practice. It involves, at the very least, identifying relationships between variables in the data, understanding the reasons why those variables behave the way they do, and then forming conclusions by synthesizing multiple pieces of information gathered across multiple lessons. The system of epistemic practices the teachers used to support this inquiry practice is shown in Figure 6. As I discussed above, both teachers supported *identifying* and *explaining* but only Sherry supported *forming generalizations*. In both classrooms, the bulk of the discussion time was spent on *identifying* and *explaining*, with teachers alternating between these two practices as they progressed through the time periods in the graphs. Sherry then supported *forming generalizations* as a way to synthesize what students had learned from the food web and data analysis activities.

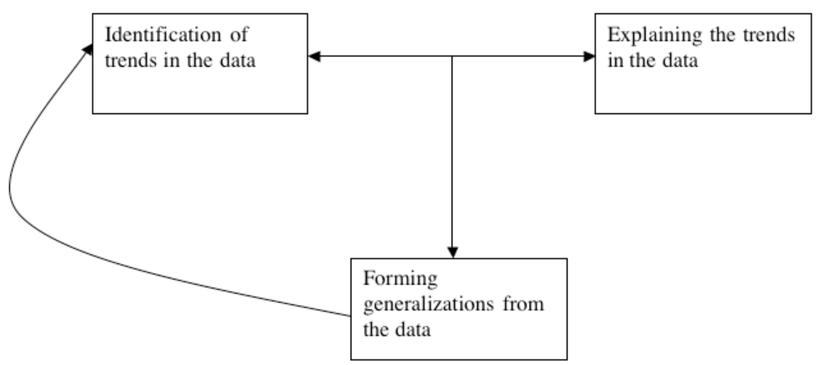


Figure 6. System of epistemic practices for *data analysis*.

The system of epistemic practices in Figure 6 is one way the inquiry practice of *data analysis* could be supported. Denise and Sherry deconstructed the complex inquiry practice into distinct reasoning steps and thus made it more accessible to students. In the written curriculum, the main goal of the lesson was to explain the trends in the data. However, both teachers saw a need to support the use of scientific terms such as *stable* and *unstable* in interpreting the data.

Therefore, they spent the majority of the class discussion supporting the *identifying* practice. The perspective of epistemic practices was useful in this case in understanding the challenges the students faced in this inquiry practice and, therefore, where the teachers placed most of their support. However, as I argued in the previous section, each epistemic practice shown in Figure 6 is itself a site for support along multiple dimensions. Therefore, in the next section I will explore the nature of Denise and Sherry's support for the epistemic practice of *explaining trends in the data*.

Denise: support for explaining trends

As with her support of *making predictions* above, Denise has fairly structured interactions with her students. Despite the structured nature of her interactions, however, she is able to accomplish complex reasoning with her students. In this lesson, new scientific vocabulary was introduced that could potentially represent challenges to Denise's students given her concern about language issues. In the following example, the students are working in groups to analyze the graphs in Figures 3 and 4 before coming together as a whole class to share their analyses. Denise is helping one group with their interpretations:

31:30 into the class
275 Eric: What would this be called? Stabilized? Because it went up and down.
276 T: So increase and then a decrease. But don't forget—remember what you said about our predictions. Lampreys went in and ate the trout so in the meantime what happened to the whitefish? You said it.
277 Eric: It went up.
278 T: It went up. And then after a while what did it do?
279 Eric: It decreased.
280 T: Why?
281 Eric: Because lampreys turned on them
282 T: Right. You can use more than one word. You can say like there's a sharp increase, and then a…
283 Larry: decrease
284 T: Ok you can say stuff like that.

In this example, there is evidence of Denise providing support along all three dimensions. In the cognitive dimension, Denise uses several strategies to communicate the reasoning involved in this practice. In line 276, she reminds Eric that there is more to this practice than identifying the trends in the data. She says "but don't forget—remember what you said about our predictions". In the beginning of this lesson, students were to make predictions about the trout, whitefish, and chub populations after the sea lamprey was introduced. After they made their predictions, students then analyzed the data. In line 276, Denise tries to tie Eric's prediction about the trout population to the trend he identified in the data. She does this by structuring this interaction around the original predictions and thus communicating that Eric needs to ground his interpretations in the interactions between the lamprey and the trout. Denise then probes Eric to articulate a chain of events in lines 278-282. In this way she co-constructs the narrative with Eric that explains the trend in the data for this particular time period. As in her support of *making predictions from a model*, Denise uses fairly structured interactions in this example to accomplish the cognitive aspects of explaining the trends in the data.

In the social dimension, Denise uses two strategies to co-construct the narrative of events with Eric. Denise first probes Eric to repeat his previous answer, thus validating his ideas in order to build on them. She then uses his exact words in line 278 to indicate his role in the building of this narrative. In line 275, Eric only asks a question about the correct word to use to describe the trend in the data. By the end of the interaction, they have co-constructed a narrative that not only includes the trends in the data but the reasons underlying those trends based on the interactions between the sea lamprey and the trout.

In the linguistic dimension, Denise uses two strategies to communicate the appropriate descriptive language to use during this practice. In line 276, she revoices Eric's phrase of "it went up and down" to "increase and then a decrease". In this way, she models the kind of scientific language that is appropriate to describe the trends in the data. Eric and then Larry appropriate this language use in lines 279 and 283 when they use the terms "increase" and "decrease". Finally, in line 282, Denise models the appropriate language use by saying "you can say like there's a sharp increase". By adding the word "sharp", she indicates the appropriate level of description that should be used in students' analyses.

TABLE 12. Cognitive, social, and linguistic rules for Denise's support of *explaining trends in the data*

Dimension	Rule	Strategy
Cognitive	• Reasoning is grounded in the sea lamprey interactions	• Structuring around content
Social	• Students and teachers co-construct the narrative of events	• Probing to repeat an answer • Repeating a students' exact words
Linguistic	• There are appropriate scientific descriptors • There is an appropriate level of description	• Revoicing using scientific terms • Modeling language use

Although Denise's interactions with her students seem fairly structured, we can better understand the complex reasoning she engages her students in by using my model of inquiry as a Discourse. In the above example, Denise does not simply tell Eric the reason behind the trends he observes. Instead, she reminds him of his initial predictions and pushes him to make connections between those predictions and his observations. She carefully structures this interaction to remind him of important information they have collected from the food web and uses his own words to co-construct the complete interpretation of the data. Finally, she models appropriate language use as she gives Eric the opportunity to engage in this practice. A summary of the rules and the strategies she uses to communicate those rules is in Table 7.

This interaction is an example of a teacher balancing the demands in all three dimensions in order to support the student in the practice of explaining trends in the data. This example points to two challenges in supporting inquiry practices. The first is the importance of the cognitive, linguistic, and social dimensions in accomplishing this practice. Part of explaining trends in the data is understanding the trends in light of information previously learned. Therefore, part of the teacher's job in supporting this practice is helping students synthesize what they have learned thus far. Denise did this as she reminded Eric of the predictions he had made in a previous activity. Explaining trends in data also requires a certain type of descriptive language use that students may or may not be familiar with. Therefore, part of the teacher's job in supporting this practice also includes getting students to use this type of language. The second, which is one of the biggest challenges in inquiry science, is to give students the opportunity to engage in the practice at the same time that they learn *how* to engage in the practice. Denise provides support for the social dimension of this practice by structuring her own role as co-constructer and synthesizer of ideas so that Eric could engage in the practice of explaining the trends in the data with her support.

Sherry: support for explaining trends in the data

Applying my model of inquiry as a Discourse to Sherry's enactment of *explaining trends* highlights the importance of the system of epistemic games teachers used to support the larger inquiry practice of *data analysis*. In the following example, Sherry is able to build on the work accomplished in the *identifying trends* practice in the *explaining* practice. Specifically, she does not have to define the terms "stable" and "unstable" because this was already done *identifying trends*. In the example below, students are analyzing the trout population for a particular time period.

3:50 into discussion
49 T: Ok. So in this time period, what happens? Annie?
50 Annie: It's an overall decrease
51 T: Overall decrease? Stable or unstable?

52 Annie: Unstable.
53 T: Ok. Why do you think that happened?
54 Annie: Because the sea lamprey started eating them.
55 T: Ok. Anybody disagree with that? Does this coincide with the time when we look at…
56 Ss: Yes
57 S: That's when the sea lamprey…
58 T: [puts up overhead of lamprey data] Whoa. Look.
59 Jen: What is that, lamprey?
60 T: Mm Hm.
61 Jen: So it's going up. It's eating more up there of that—what is that, trout?
62 T: Yeah. This is trout. Now this is not perfectly—now I don't know if it's like this or…[T has trout and lamprey graphs on top of each other on the overhead]
63 S: 1970, that's when it starts like—it took time for it to decrease.

Sherry uses two strategies to guide students' cognitive reasoning in this practice. First, she probes Annie for reasoning in line 53 and thus communicates the cognitive rule that identification of the trends in the data is not the only part of this practice: they need to create a narrative of events from the data as well. By asking "why do you think that happened", she cues the students to think about the reason behind the trend. She reinforces this by putting up the overhead of the sea lamprey data in line 58. In line 62 she puts the data for the trout population on top of the data for the sea lamprey population so that students can consider the data simultaneously. By doing this, Sherry models how to synthesize the graphs and consider both the trout and the sea lamprey data simultaneously in students' interpretations. After she does this, a student in line 63 says "it took time for it to decrease", meaning that the trout population took some time to decrease after the sea lamprey population peaked and began feeding on it. Sherry's use of modeling and probing strategies seemed to successfully get students think about the reasons behind the trends in the data.

In the social dimension, Sherry uses the strategy of eliciting multiple responses to indicate that students' role in this discussion is to be critical, active participants. She asks in line 55, "anybody disagree with that?" This is a consistent strategy that she uses throughout the unit to communicate students' role in discussions. She expects students to argue with each other and not respond only when she asks a question. We can see this in line 61 where Jen first offers her interpretation once Sherry puts up the overhead of the sea lamprey data. Then in line 63 another student offers her interpretation of the data when she says "1970, that's when it starts like—it took time for it to decrease." These interpretations are unsolicited by Sherry but students seem to have a joint understanding that their role in this discussion is of active participant rather than passive listener.

Most of the linguistic support for this practice occurred when Sherry supported *identification*. This makes sense because that is where students needed to establish the language for describing the trends in the graphs. In the following example, which took place during *identification*, Sherry attempts to lay ground rules for the use of the terms "stable" and "unstable":

:16 into the class

1 T: Trout. Tell me what happened. Ok. Who's going to tell me—Andy because you're always so quiet, you get to talk now.
2 Andy: The trout population before 1944 was stable, 6000 to 7500.
3 T: It was stable what?
4 Andy: It was stable between 6000 and 7500 metric tons.
5 S: 6000 to 7000?
6 T: What about '44-'63? Does anyone disagree with what Andy just said?
7 Jen: what was the time period what was the time period?
8 T: Does anyone disagree with what Andre just said?
9 Mary: Um, I believe my group put this too, for the stable—we put unstable.
10 T: So you think it's unstable why?
11 Mary: Because it doesn't stay in one place.
12 Jen: It doesn't have a pattern, it's not, it's not like between, it's not in that range and just like it has no high, no peaks, it's not like up down, up down you know.
13 Kevin: It looks stable to me.
14 Jen: I don't think that's stable.
15 T: How many people think that's stable? [some ss raise hands]
16 T: How many people think it's unstable? [some ss raise hands]
17 T: Ok. Here's my feelings on this and I may be wrong…Um, if you can justify why you think it's unstable or why you think it's stable, I think it's ok. Clearly I mean there's

going to be some that are very obviously stable and there's going to be some that are very obviously unstable. This next one, is it stable or unstable?

18 Ss: Unstable

19 T: Unstable. Um, I think that if you can sufficiently support your reasoning, or show me your reasoning behind why you think –there's no pattern, it falls out of the range—I think that I would, I would give you credit for it. So don't panic if you've got something different than what other people have as long as you can defend what you say. And that works in my room, it doesn't always work in everybody else's room. Some teachers like a definitive, everyone's got to say the same thing…

In the above example, there is clear linguistic support for defining the terms "stable" and "unstable". The students begin to have a disagreement about whether or not to define a certain trend in the graph as stable or unstable. Sherry picks up on this controversy and asks how many students labeled the data as stable and unstable. Then she provides explicit support by explaining that as long as students have a reason for labeling some data stable or unstable, she will accept their answer. Furthermore, she gives examples of acceptable reasons for calling something unstable: "there's no pattern, it falls out of range". In this way, she communicates to students that there are multiple acceptable interpretations of data as long as one is clear about the definitions of the scientific terms from which one is working.

TABLE 13. Cognitive, social, and linguistic rules for Sherry's support of *explaining trends in the data*

Dimension	Rule	Strategy
Cognitive	• Reasoning is grounded in the sea lamprey interactions • Need to consider multiple data sources simultaneously	• Structuring around content • Modeling the use of data for analysis
Social	• Students' roles are as active and critical participants	• Eliciting multiple responses
Linguistic (*from identification)*	• Multiple interpretations of "stable" and "unstable" are acceptable	• Explicit communication of rules

This analysis of Sherry's support of *explaining trends* points to the ways in which the teachers in this study built a system of epistemic games to support the larger practice of *data* *analysis*. Because there was not much linguistic support during this epistemic practice, *explaining trends* seemed to build on the linguistic rules established during *identifying trends*. Sherry clearly communicated appropriate guidelines for the use of the scientific terms "stable" and "unstable" during *identifying trends*. The students then appropriated these terms during the discussion where they shared their interpretations.

Discussion

I began this study by asking the question *what is the nature of teachers' support of inquiry practices as they enact an inquiry-based curriculum*? I hoped to understand both the types of challenges that arose for teachers as they enacted an inquiry-based curriculum and the ways in which they dealt with those challenges. In order to describe these challenges, my analysis took place in two parts. The first was to describe teachers' attempts to support inquiry in terms of epistemic practices. I described how this perspective afforded a precise language to talk about which practices teachers were attempting to support at the same time we furthered our understanding of one form that support may take. Secondly, I took the perspective of inquiry practices as part of the Discourse of science, with underlying values and epistemologies that were probably unfamiliar to students. I explored the extent to which cognitive, social, and linguistic dimensions of my framework were able to describe teachers' practices and found that the dimensions did capture important aspects of their practices. Teachers moved seamlessly between dimensions in their attempt to support students, and their attention to each dimension was at times very subtle. Both perspectives—epistemic practices and inquiry as a Discourse—furthered our understanding of both the challenges teachers may face during inquiry and the strategies they use to deal with those challenges. I discuss some of these below.

I found two ways in which teaching tensions might occur as teachers enact inquiry curricula. The first was when teachers try to balance the demands for each epistemic practice. If teachers elaborate broad inquiry practices into smaller epistemic practices, they may get "stuck" in the more basic practices without ever moving on to the more ambitious ones. For example, I saw both teachers using similar epistemic practices to support the *data analysis* inquiry practice. Although the system of epistemic practices shown in Figure 6 makes sense and could potentially lead to ambitious types of reasoning about data, the teachers spent the majority of the classroom time on the practice of *identifying trends in the data*. If students have trouble with initial steps of the practice, they may not get the opportunity to engage in the more ambitious parts of the practice such as forming generalizations from trends in the data. Teachers need to balance students' need for support in understanding analytical tools with moving on to the more challenging tasks of using those tools to do important cognitive work.

This analysis of epistemic practices contributes to existing work in mathematics on teaching for deep understanding because it specifies points of instruction at which teachers might resort to procedural strategies rather than teaching underlying scientific principles. For example, in while supporting the practice of *identifying trends in the data*, Sherry spent substantial classroom time discussing the meaning of "stable" which left little time for reflecting on the reasons behind the trends in the data. One way Sherry could have resolved the debate was to have students converge on one way to identify "stable" trends in the data, but she seemed unwilling to cut short the debate among students. Therefore, this analysis highlights the importance of the teacher's role in moving students through the system of epistemic practices in order to reach those more ambitious parts of the practice.

Another possible source of teaching tensions I found through my analysis was when teachers need to balance the demands from the cognitive, social, and linguistic dimensions within a single epistemic practice. My framework allowed me to articulate some of the demands from each dimension, such as signaling to students next steps in reasoning, supporting students' roles during discussions, and defining scientific terms. My findings contribute to existing studies on teachers managing tradeoffs in teaching (Sandoval & Daniszewski, 2004; Windschitl, 2002; Lampert, 1995; Ball, 1993). As I saw in Denise and Sherry's enactments, which dimensions teachers emphasize and how they provide support along each dimension may depend on multiple factors such as the teacher's perceptions of the needs of her students and the teachers' own understanding of science and inquiry. However, balancing these needs is a matter of tradeoffs: work in one dimension may take away classroom time and energy from work in other dimensions. These demands may also be in tension with each other. For example, Sherry's fielding of multiple students' responses seemed to be in tension with converging on the important take-away ideas from the discussion. Further work needs to be done to explore the reason for teachers' choices to emphasize certain dimensions over others. I believe this study is a first step in articulating the types of challenges that might arise for teachers during inquiry and how teachers might meet those challenges.

Besides helping to explain how and why teaching tensions may arise for teachers as they enact inquiry curricula, my analysis pointed to some interesting differences between the teachers. I found that both teachers in this study attended to all three dimensions of inquiry within a single epistemic practice, but in different ways and to different extents. Denise seemed to take a more structured approach, paying particular attention to the linguistic dimension during her enactment. As I described earlier, this may have had to do with the large population of second-language learners in her class and her perception of their language needs. I also found that Denise communicated aspects of the cognitive dimension through structured interactions with her students. Again, this may have been a reflection of her perception that her students needed this type of heavy scaffolding because of language difficulties and their unfamiliarity with inquiry practices. Perhaps because of her attention to the linguistic dimension and the extent to which she provided such structured support, Denise seemed to provide little support in the social dimension. While she included students in discussions, she did not dramatically renegotiate social roles in the classroom.

In Sherry's class, I again found her attending to all three dimensions within a single epistemic practice, but paying particular attention to the social dimension. She seemed very interested in fostering widespread participation among the students during discussions. However, this left little class time for consensus building and reflection on important scientific ideas. Sherry's emphasis on the social dimension of inquiry may reflect classroom norms already established prior to starting the *Struggle* unit—students may have had the expectation to share their ideas and what I observed in Sherry's class was simply a continuation of that norm. Or, this emphasis on the social dimension may reflect Sherry's own belief that students in science should be encouraged to share their ideas instead of the teacher being the sole authority. Whatever the reason, participation itself does not necessarily imply constructive reasoning about scientific ideas. Sherry needed to balance participation with covering the important content ideas at hand and engaging students in the cognitive tasks of making predictions and analyzing data.

Understanding inquiry practices as systems of epistemic practices that are themselves multidimensional therefore lends some insight into the multiple challenges teachers need to balance as they enact an inquiry curriculum. Teachers need to consider where in an inquiry practice students may need the most support while still making sure to engage students in the more challenging and complex parts of the practice. Within each epistemic practice, teachers need to communicate rules for each dimension in order to support students' participation in those practices. My analysis was also able to detect some interesting differences in the teachers, suggesting that teachers' choices on how to achieve a balance between the multiple demands of inquiry practices may involve such factors such as a teacher's perception of the needs of her students, her own familiarity with the relevant content and process goals of the curriculum, and the state of the curriculum itself. The choices teachers make for how to achieve this balance has some implications for students as well, which I explore in the next section.

Finally, my analysis lends some insight into why it may be so challenging for teachers to reach the "ideal" inquiry components listed in the introduction. My analytical framework articulates some of the major challenges teachers may face as they enact inquiry curricula. Teachers need to make decisions about how to best articulate reasoning steps in complex inquiry practices. They also need to be aware of and balance the demands from the cognitive, social, and linguistic dimensions. In addition, teachers may need to lay conceptual groundwork in each of these dimensions if their students are unfamiliar with scientific ways of reasoning, interacting, and using language. Therefore, Denise and Sherry—while they were not examples of exemplary inquiry teaching—may be on the "teacher-centered" end of a teaching trajectory that ranges from very teacher-centered inquiry to very student-centered. My analysis allows a realistic understanding of what it may take to put inquiry in place in classrooms and why it may be so challenging.

Implications for students

My analysis of inquiry practices consisting of cognitive, social, and linguistic dimensions has implications for students' participation in these practices and contributes to our understanding of why it may be so challenging for students to engage in them. Here I reflect on Aikenhead's (1996) characterization of learning science as "border crossing" from students' own "subculture" into the "subculture of science". Aikenhead defines "culture" as "the norms, values, beliefs, expectations, and conventional actions of a group" (p.8). According to this definition, inquiry science fulfills the definition of a culture: there are norms for practices that encompass the values, beliefs, expectations, and conventional actions of a group of people—scientists. However, students come from many subcultures that may be defined by their age, peer groups, ethnicity, and gender. All of these subcultures have their own norms for action that may be very different from those of scientists. Therefore, learning science can be conceptualized as crossing the border between a student's culture(s) and that of science. In order to make this border crossing, however, students need help. Indeed, just as their peers help them understand "rules" for participating in games and play, students need help from teachers and curriculum materials for understanding the rules for participating in scientific inquiry practices. Students cannot be expected to intuitively know these rules simply by being exposed to engaging investigative contexts or curriculum materials (Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999). However, inquiry investigations often immerse students in investigations without explicit support for how to use the scientific tools of inquiry to engage in those investigations.

In this study I hypothesized that teachers might attempt to facilitate this "border crossing" by communicating rules for inquiry practices in three dimensions: cognitive, social, and linguistic. The challenge for teachers is how to provide support in all three dimensions for a single practice. For example, students are often told to critique each others' work without being taught explicitly on which criteria they should evaluate one's work, how to apply those criteria to the investigation at hand, how to give suggestions for future directions. Simply knowing the definition of the term "evidence" does not mean that the student knows how to critique the strength of one's evidence in relation to one's claim, or how to give suggestions for what evidence would make one's argument stronger. Therefore, support in the cognitive task of critiquing another's claim needs to be coupled with support in the linguistic dimension of what terms like "critique" and "evidence mean. Students also may need support in understanding what their roles might be in such a conversation—to provide criticism on the basis of one's claims and evidence rather than on a personal basis. My framework provides a way to characterize the types of support teachers provide as they facilitate students' border crossing from their own subcultures into the subculture of science.

However, the support the teachers gave was seldom explicitly stated. I began this study expecting to find explicit support in each of these dimensions. What I found, instead, were mainly tacit cues that teachers used to communicate complex rules within each dimension. This raises some important issues in considering how to support students in inquiry practices. For example, if students are rarely explicitly taught how to engage in a practice, how and when do they learn the rules for engaging in that practice? How can explicit instruction be built into curricular materials for both teachers and students? What would this explicit instruction look like?

These issues have implications for making inquiry accessible to all students, as is the stated goal in reform documents such as the *National Science Education Standards* (NRC, 1996). Students for whom the subculture of science is more congruent with their out-of-school subcultures may have an easier time with this "border crossing". Therefore, they may benefit from the tacit support I found the teachers using to communicate rules in each dimension. For other students, however, their unfamiliarity with scientific practices may necessitate more explicit instruction of the rules for those practices. It is not clear, however, what form this explicit support should take and at what points in instruction it should occur. Further work needs to be done to empirically explore this issue.

This work therefore points to implications for design of inquiry-based curricula. A challenge that arises in response to my findings is how to build supports into curriculum materials for students and teachers for how to engage in inquiry practices. This issue is complex because any design needs to take into account teachers' particular instructional contexts and the adaptations they need to make in response to the needs of their students. Barab and Luehmann (2003) argue that "a central challenge for designers is how to develop curriculum and teacher scaffolds that support teachers in the adaptation of these curricula to meet the needs and goals of their local context and culture" (p. 461). As with Denise and Sherry, the dimensions they chose to emphasize may have been a reflection of their instructional contexts. Therefore, how can curriculum materials support teachers in adapting the curriculum to their particular needs?

My analysis of Denise and Sherry's enactments using my multidimensional framework allowed some insight into the types of challenges that might arise for teachers as they attempt to enact an inquiry-based curriculum. In this study I began to explore the strategies the teachers used to deal with these challenges and the ways in which each teacher managed tradeoffs between the demands of each dimension. What I hope to articulate in future work is a more elaborate description of the strategies teachers use to communicate rules at each dimension and what this strategy use tells us about how teachers manage teaching tradeoffs that arise. I also hope to explore the effects of teachers' strategy use on students' perceptions of inquiry practices. Finally, I hope to explore the synergistic nature of the dimensions themselves: does work in one dimension help do work in other dimensions? Ultimately, the goal of this work is to further my understanding of what it takes to bring inquiry-based science into the classroom—how teachers operationalize the designed curriculum in a way that makes complex practices and content accessible to all students.

CHAPTER THREE
ASPECTS OF INQUIRY IN SYNERGY: HOW TEACHERS ACCOMPLISH MULTIPLE GOALS OF INQUIRY

Introduction

Science education reform emphasizes learning science through inquiry as a way to engage students in the processes of science at the same time that they learn scientific concepts (NRC, 1996). However, inquiry involves practices that are challenging for students because they have underlying norms with which students may be unfamiliar. Inquiry represents a dramatic departure from the image of traditional science teaching in which the teacher lectures, the students read from textbooks, and students conduct the same laboratory exercise in pursuit of the "right" answer (Schwab, 1966; NRC, 1996). Inquiry-based science requires students to engage in new types of scientific practices within the context of a complex investigation, thus combining the need for deep content understanding and the skills to conduct meaningful investigations (Edelson, Gordin, and Pea, 1998). Therefore, various challenges arise for students as they learn to engage in these new types of practices. For example, students need to reason in new ways about complex scientific concepts, use these concepts to ask questions and guide the design of investigations, and gather evidence to support the conclusions they make from these investigations.

We want students to participate in these practices because the goal of science education should be to create scientifically literate citizens who are critical of the world around them, can make informed decisions about scientific issues that affect their everyday lives, and use scientific methods to gather new information and answer questions for themselves (NRC, 1996). Participating in inquiry science practices gives students the opportunity to engage with both the content and processes necessary to develop this literacy. However, putting these practices into action in the classroom is a complex process of which we as a field need a better understanding. Inquiry practices are multidimensional in nature (Tzou & Reiser, paper 1; Longino, 1990; Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002), encompassing not only reasoning components but linguistic and social components as well. How do students come to understand how to participate in these practices? How do teachers support students in their participation in these practices? Answering these questions will help curriculum designers, teacher educators, and teachers better design learning environments to support students' inquiry participation in inquiry practices.

In this study we will characterize teachers' attempts to support students' participation in inquiry practices and explore the dimensions along which this support plays out. I define inquiry from the *National Science Education Standards* (NRC, 1996) to be when

> students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. (p.2)

Inquiry therefore encompasses many types of practices, each of which represent a site where teacher support may be necessary for students' participation. Inquiry practices involve students in opportunities to construct their own scientific knowledge. However, in order to understand, from an analytical perspective, what it means to operationalize these practices in classrooms, we need to first explore what aspects of scientific practices are important to be enacted in classrooms. Since we cannot replicate a scientific community in classrooms, what are the relevant aspects of scientific practices that may be important to bring in to classrooms?

To answer this question, I draw on literature from both the nature of science and research in science education. The nature of science literature is important here because I take the perspective of science that Lehrer and Schauble (in press) call "science-as-practice". This perspective draws from observational studies of scientists in action and recognizes the importance of engaging students in scientific practices. Participation in these practices, however, necessitates students' learning some of the norms of scientific practices such as using representations, communicating about phenomena, and using established methods for investigating scientific problems (Lehrer & Schauble, in press). The nature of science literature is useful to give us some insight into these norms for scientific practices and the aspects of scientific practices that may be important to bring to classrooms. Therefore, I will first explore what philosophers of science say about the nature of science practices themselves so that we can have a clear definition of what the practice entails. In what ways are they multidimensional? What implications does this have for the enactment of inquiry practices in the classroom? I will then explore the ways that research in science education has proposed putting these practices into the classroom. What practices are essential for students to participate in if they are to experience the authentic nature of knowledge construction in science? Finally, I propose a perspective of science as a culture in order to explain the complexity of teaching and learning science as inquiry. I draw on my earlier work and present a framework for characterizing the multidimensional nature of inquiry practices and teachers' enactments of inquiry curricula.

Understanding the nature of scientific practices

Many science educators have argued that science education should be an education in scientific ideas but, more importantly, an education about the practices of science itself: scientific ways of asking and answering questions, scientific ways of forming conclusions (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002). This, in turn, would lead to scientific literacy in which students can use these ways of gaining knowledge to be more critical of the world around them (NRC, 1996). The question remains, however, of which scientific practices and which aspects of those practices are most important to import into classrooms. Literature in the philosophy of science and scientific literacy about the nature of scientific practices can shed some light on the aspects of scientific practices we may want to emphasize in classrooms and why these aspects are important to constructing scientific knowledge. Mainly this literature emphasizes that inquiry practices are themselves multidimensional and involve not only aspects of complex reasoning but also social practices and unique ways of using language. In this section I explore one way in which scientific practices can be multidimensional from the perspective of philosophy of science and ask what implications this may have on the teaching and learning of science as inquiry.

Recent literature in the philosophy of science emphasizes the social nature of science as opposed to the positivist view of science that argues for scientists making objective, "true" observations about the world. Scientific practices are by their very nature social practices in several respects. First, an individual needs to be apprenticed into the "traditions, standards, techniques, and vocabulary" of the practices of science (Grene, 1985, p. 14). This necessitates an interpersonal relationship between a teacher and a learner. One can imagine the classroom teacher and the curriculum materials playing similar roles for students in this sense, helping students participate in both the scientific content and the practices that are situated within certain "traditions" of science. Second, science is a social endeavor because scientific knowledge is the product of many individuals working simultaneously—sometimes collaboratively, sometimes competitively—on the same problem. In some cases, scientific problems are so big that certain scientists only work on certain aspects of those problems and "the integration and transformation of these activities into a coherent understanding of a given phenomenon are a matter of social negotiation" (Longino, 1990, p. 67). In an inquiry curriculum, different students frequently need to work on different aspects of a problem and come together at the end to integrate their collective knowledge. Or, students frequently come together at the end of an investigation to compare their work around the same problem. Both of these processes necessarily involve some kind of social negotiation about what makes a convincing argument, which evidence provides the strongest support for a claim, or how to integrate the collective knowledge into a comprehensible explanation of some phenomenon. Third, science is social in that scientific breakthroughs depend on previous work done by other scientists and rest on a tradition of understandings that have been validated by the community of scientists. Finally, the peer review process, which determines what studies get funded and which articles get published, is the most clearly social aspect of science. After an article is published, it can become "scientific knowledge" if its experiments are repeated and validated by others in the community, and if its findings are used to further the findings of other scientists. In the classroom, students frequently need to use evidence to "convince" their peers of the validity of their findings, mimicking this process. Scientific findings are therefore not truly "findings" unless they are shared with the community for critique and validation.

Once again, the science-as-practice perspective described by Lehrer and Shauble (in press) is relevant here because it describes the process of scientific knowledge construction in the following way:

> theory development and reasoning are components of a larger ensemble of activity that includes networks of participants and institutions…specialized ways of talking and writing…development of representations that render phenomena accessible, visualizable, and transportable…and efforts to manage material contingency, because no theory ever specifies instrumentation and measurement in sufficient detail to prescribe practice.

Scientific practice therefore involves multiple dimensions of practice: reasoning, social networks of participants, specialized uses of language and representations, and using certain instrumentation to test theories. In order to explore how these might be carried out in classrooms, it might be useful to illustrate an example of an inquiry practice and the ways in which they are multidimensional. One example of an inquiry practice that has both social and cognitive aspects to it is argumentation (Driver, et al, 2000). Argumentation, or being able to

> articulate reasons for supporting a particular claim; to attempt to persuade or convince their peers; to express doubts; to ask questions; to relate alternate views; and to point out what is not known (p. 291)

is one of the central ways in which scientists communicate and critique each others' claims. It is through this process of social knowledge construction that scientific knowledge becomes public, that scientists collaborate to solve problems, and that weak claims are distinguished from strong ones. In order for students to participate in the process of scientific knowledge construction, then, they must learn how to participate in the social process of argumentation. However, how might we operationalize this in the classroom? Which aspects of argumentation are most important for students to engage in? How might a teacher support this practice while at the same time keeping the scientific content ideas central to the task? Students and teachers may need to negotiate their classroom roles, the role of "facts", and the importance of persuasiveness in making scientific claims. All of these aspects of the practice of argumentation involve students in not only complex reasoning but also social negotiation with their peers.

In this study, I assume that inquiry practices take on many of the characteristics of authentic scientific practices. For example, students may need to critique each others' claims based on the strength of the evidence in support of that claim. This is similar to the process of peer review in which scientists review and critique the work of other scientists on the basis of experimental design, evidence, and other factors. The question then arises of how teachers support the social aspect of inquiry practices at the same time that they engage students in complex reasoning tasks and in learning complex scientific content. Does support in one dimension interfere with or take classroom time away from support in another dimension, or are there ways in which they can be mutually supportive? What might it look like in classrooms when teachers attend to multiple dimensions simultaneously?

Models of teacher practice in science inquiry classrooms

Existing research on teachers' practices in enacting science education reform in classrooms frequently gives broad guidelines for how teachers should support inquiry (Engle & Conant, 2002). While these guidelines are useful as guiding principles, we as a field need more research into the day-to-day workings of science teachers' enactments of inquiry practices in order to better design learning environments to support these practices (Crawford, 2000; Flick, 2000; Beeth & Hewson, 1999). For example, Engle and Conant (2002) present a framework for designing learning environments to foster productive disciplinary engagement in science classrooms. The four principles of their framework are: (1) problematizing, (2) authority, (3) accountability, and (4) resources. Although these are useful heuristics for design—for example, setting up opportunities for students to pursue scientific problems or designing activities that increase students' accountability to each other, the question remains of *how* teachers manage to operationalize these principles in real classrooms.

This study attempts to systematically describe how teachers operationalize the multidimensional nature of scientific practices. I use a framework presented in my earlier work (this dissertation, chapter 2) as a way to characterize the dimensions of inquiry teachers attend to as they attempt to support students in inquiry practices. This framework, which I describe later, gives us a way to understand how teachers may attend to multiple dimensions simultaneously and the types of support teachers may be providing even in moments that seem more teacher-directed than commonly accepted views of inquiry teaching. I argue that this description of practice may be useful for a realistic, day-to-day exploration of what it takes to put inquiry into classrooms and may therefore help curriculum designers, teacher educators, and teachers better design learning environments to support students in inquiry practices.

"Border crossing" into inquiry science

We therefore need a way to characterize inquiry science that takes into account the complexity of these practices so that we can gain a better understanding of both the challenges that might arise for students and teachers in inquiry and how to support students in learning how to participate in inquiry practices. To this end, I take the perspective of science as a culture, using Aikenhead's (1996) definition of culture as "the norms, values, beliefs, expectations, and conventional actions of a group" (p.8). According to this definition, inquiry science fulfills the definition of a culture: there are norms for practices that encompass the values, beliefs, expectations, and conventional actions of a group of people—scientists. I assert that it is partly because of these norms for practices that inquiry science is so challenging for students: while students may be familiar with "explaining" something to their peers, they may be less familiar with constructing a "scientific" explanation which is evaluated on the basis of evidence. Therefore, although inquiry science is a way for students to engage with complex scientific content through meaningful and authentic investigations, we cannot assume that simply immersing students in engaging investigational contexts will provide enough support for students to understand *how* to participate in complex scientific practices (Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999).

How do students come to understand how to participate in these practices? Aikenhead (1996) argues that for students, learning science is a process of “border crossing into the subculture of science”, in which students learn the norms and expectations within the culture of science and thus cross the border between their own subcultures—defined by their peer groups, ethnicities, gender, and other factors—and that of science. Teachers and curriculum materials play pivotal roles in this border crossing, making the “rules” for practices within the subculture of science explicit to students. The question, therefore, is which rules teachers make explicit, how they do so, and how we can characterize these rules so that we can build better supports into curriculum materials and professional development efforts for teachers.

Teaching inquiry as balancing demands across multiple dimensions

In a previous study (Chapter 2, this dissertation), I introduced a framework to characterize how teachers might communicate rules for inquiry practices. This framework situated inquiry practices in the Discourse of science (Gee, 1996). As part of the Discourse of science, inquiry practices embody many of the epistemological values of the community of practice of scientists. As such, inquiry practices are not simply cognitive tasks for students to engage in; instead, they involve certain norms or “rules” of practice that reflect the values of scientists. For example, scientific explanations are very specific ways of explaining phenomena: an explanation in science involves making a claim and backing up that claim with evidence. This differs dramatically from the everyday use of explanations. Therefore, in order for students to fully participate in inquiry practices, teachers need to somehow communicate these aspects of the practice to students.

I found that teachers’ practice could be described in terms of cognitive, social, and linguistic dimensions. I defined the cognitive dimension as the reasoning processes involved in an inquiry task. For example, in an inquiry task of data interpretation, cognitive aspects would include finding patterns in data, linking those patterns to phenomena, and constructing explanations of those patterns based on scientific principles. I defined the social dimension as any aspect of the task that involved roles and responsibilities for students and teachers. Because inquiry tasks often involve students working collaboratively on complex investigations (Hogan 1999), students take on sometimes unfamiliar classroom roles as they have more responsibility for their own learning. Finally, the linguistic dimension was defined as any aspect of the inquiry task that involved scientific language use. Because learning science involves, in part, learning the language of science (Lemke, 1990; Halliday, 1998), the linguistic dimension seemed to linked strongly to the cognitive dimensions of inquiry tasks. For example, in order to include evidence for a scientific explanation (a cognitive task), students needed first to understand what the terms "evidence" and "explanation" meant in the context of the investigation.

By using this framework as a lens to characterize teachers' enactments of an inquiry-based curriculum, I found that the teachers in this study attended to aspects of inquiry practices that involve all three dimensions. However, this study also highlighted the need for teachers to balance the demands of all three dimensions as they proceeded through the curriculum. For example, if a teacher provided very structured cognitive support for her students, walking them through the steps in a practice, this may have left little classroom time and energy for students to interact with each other in a collaborative way in the social dimension. While the demands in each dimension may be in tension with each other, are there also ways in which they mutually support each other? The literature from the philosophy of science suggests that the dimensions might be synergistic, that work in the social dimensions for example may actually strengthen students' work in the cognitive dimension. Furthermore, what does it look like in the classroom when teachers support multiple dimensions simultaneously? I will explore these points in this study.

Summary: Exploring the intersection of inquiry dimensions

I therefore situate this work at the intersection of perspectives from the nature of science and research in science education. My perspective of inquiry science as a culture assumes that teachers need to balance demands across cognitive, social, and linguistic dimensions, managing tradeoffs between these dimensions based on various factors such as the ones I described above. In this study, I explore the ways in which teachers facilitate students' "border crossing" into the subculture of science by communicating rules for multiple dimensions simultaneously. While my previous study (Chapter 2, this dissertation) described the cognitive, social, and linguistic dimensions as separate dimensions, in this study I explore the possibility that the dimensions may intersect, easing the burden on teachers so that they may accomplish multiple goals simultaneously. For example, are there ways in which support in the linguistic dimension can actually facilitate students' cognitive reasoning? Or are there ways in which teachers can support students' collaboration and interaction while at the same time supporting students' cognitive reasoning?

By exploring the ways in which these dimensions may intersect, I am also exploring the utility of my analytical framework in describing the nature of the inquiry practices themselves. If teachers are able to support students in the cognitive and linguistic dimensions simultaneously, what does this mean about the cognitive tasks themselves? Are there aspects of those tasks that are inherently linguistic? If so, how may a teacher operationalize that in her classroom? Likewise, if teachers are able to support students in the cognitive and social dimensions simultaneously, does that point to inherently social elements within a cognitive task, aspects of the task that could not be accomplished without a community of peers? What does it look like in classrooms when teachers attend to multiple dimensions simultaneously?

Research Question and data analysis

In this study I explore how teachers support students in inquiry practices through the multiple dimensions of inquiry practices. I ask the question: *how do the multiple dimensions of inquiry intersect?* I use the term "intersect" to mean the ways in which the dimensions co-occur and mutually support each other. In other words, can we find points in teachers' enactments in which they are supporting multiple dimensions simultaneously? If so, are there ways in which doing work in one dimension actually facilitates work in another dimension? In addressing this question, I am also interested in exploring how explicit teachers are in their support of inquiry practices and what this explicitness might mean in terms of challenges students face in learning how to engage in inquiry practices. Finally, I am interested in what this intersection tells us about the nature of inquiry practices themselves. I will describe teachers' practices as they enacted an 8-week, inquiry-based science curriculum for eighth grade. Although this study was part of a larger study, I will look at a small subset of teachers (n=2) in order to get detailed insight into how teachers attend to the dimensions of inquiry, how they attend to multiple dimensions simultaneously, and what they accomplish when they do.

I will explore two instances of intersecting dimensions: the cognitive and linguistic intersection and the cognitive and social intersection. I will argue that these intersections are important for two reasons. First, I believe that they represent points at which teachers are communicating authentic aspects of the inquiry practices themselves. I will use my multidimensional framework from previous work (Chapter 2, this dissertation) to describe how teachers accomplish these intersections and what they communicate about the inquiry practices when they do so. In the process, I hope to describe the ways in which the teachers operationalize the multidimensional nature of inquiry practices in classrooms. Second, I believe that these points of intersection are attempts by the teacher to accomplish important cognitive work by pulling in other dimensions of inquiry. I will explore the ways in which the cognitive dimension is synergistic with the social and linguistic dimensions and how these other dimensions actually enhance students' participation in the reasoning tasks of inquiry. I hope that this analysis will lend some insight into the complexity of supporting inquiry practices in classrooms, insight that might have implications for the design of inquiry-based learning environments.

In this study, I do not assume that the two teachers, Denise and Sherry, were always successful at balancing these challenges, nor do I attempt to evaluate them on any measure of "success" or "failure" at inquiry teaching. Instead, what I am interested in is their attempts to enact an inquiry-based curriculum, the instructional moves they make as they do so, and what aspects of inquiry they may or may not emphasize in their enactments. I am interested in the challenges posed by inquiry teaching and teachers' attempts to respond to these challenges. By attempting to make sense of teachers' practice in this way, I provide a rich description of teachers' attempts to support inquiry in order to broaden our understanding of the nature of these efforts. Because my goal in this study was to analyze how teachers attempt to support inquiry practices in real classrooms, Denise and Sherry provide a picture of strategies a teacher might use to address challenges presented by inquiry curricula for students who may not be familiar with inquiry approaches to teaching and learning.

Data Analysis

I identified lessons in the unit that the designers considered to involve challenging inquiry practices. The two teachers, Denise and Sherry, each began their enactments of the *Survive* unit with the intention of finishing all of the lessons. However, because of institutional constraints such as state testing and end-of-year activities, Sherry enacted only the first half of the unit. Since I was interested in comparing the teachers in their attempts to support similar inquiry practices, I was therefore limited to choosing lessons from the first half of the unit (lessons 1-11). A summary of these lessons is listed in Table 10 in chapter 2. The lessons I chose to analyze were lessons 3, 5, 8, 9, and 10 because of their explicit emphasis on an easily identifiable inquiry practice. An additional lesson in part 2, lesson 14, was analyzed from Denise's enactment because it was another interesting example of the practice of data analysis. I will describe this lesson in more detail later.

After I identified the lessons, I transcribed the entire lesson and did a line-by-line analysis of teachers' utterances for cognitive, social, and linguistic dimensions. Utterances could fall in to more than one dimension. Since the focus of this study was how teachers supported the overlap between dimensions, I used as a basis for this analysis only those utterances that fell into more than one category, such as cognitive and social dimensions or cognitive and linguistic dimensions. I describe this overlap in the next section. Utterances that were excluded from analysis involved teachers attending to administrative business and when teachers were discussing unrelated events with students.

Linguistic and cognitive dimensions intersect: using language as a tool

The focus of this study is to explore the ways in which the dimensions of inquiry intersect, or co-occur, and how teachers treat this intersection in classrooms as a way to support students' participation in inquiry practices. In this section I will explore one such instance of intersection, that between the cognitive and linguistic dimensions. I will explore the ways in which the teachers used language as a tool for helping students with the cognitive aspects of particular inquiry tasks.

As I argued earlier, scientific practices are themselves multidimensional. The question, however, is how teachers operationalize this multidimensionality in the classroom? For example, modeling is a scientific practice that is central to the activity of scientists and involves skills in multiple dimensions. Modeling may require students to be familiar with standard scientific ways of using language to represent phenomenon—in a diagram or a graph—to communicate one's thinking about that phenomenon. Harrison and Treagust (2000) argue that modeling is essential to scientific thinking in several ways. Scientists use models to account for and explain data and are therefore both the means by which scientists reason about data but also the result of that reasoning. In other words, models are both the methods and products of scientific reasoning. Students can also use models to account for their data (Lehrer & Romberg, 1996) or to represent their reasoning about a scientific idea. However, modeling requires that students understand the ways in which a model is both a simplification and an abstraction of the phenomenon it represents. Students must also understand the limits and affordances of models in illustrating certain aspects of a phenomenon; while a model may make obvious one aspect of a phenomenon, it may also mask other aspects. All of these aspects of modeling require students to understand standard scientific notation systems and ways of describing phenomena that may be unfamiliar to them. In order to use models to communicate their cognitive reasoning, students need to use certain linguistic aspects of science. Modeling is therefore a complex activity that is integral to the construction of scientific knowledge but may require support from teachers in multiple dimensions.

In the example of modeling, we can see how a single inquiry practice can require support from the linguistic dimension in order to facilitate work in the cognitive dimension. However, Lemke (1990) argues that one of the most difficult aspects of learning science is learning to use the language of science, to "talk science". Talking science, according to Lemke, involves not only coming to understand the specialized ways in which science uses patterns of speech, grammar, and vocabulary. In science, as in other disciplines, language use implies certain norms of action; therefore, learning to use the language of science means, in part, coming to learn how language can be translated into certain actions. Here I draw on Wertsch (1991), who argues that we all use tools, or *mediational means*, to mediate our mental functioning and that these “tools” have cultural, historical, and institutional settings in which they are created. Furthermore, mediational means and action are “mutually determining” (p. 117), meaning that we must understand mediational means in terms of the actions that they help to organize.

If we think about language as such a mediational means, we can start to understand why it may be so difficult for students to understand how to use scientific language to facilitate their reasoning about scientific ideas. As a mediational means in Wertsch’s sense, we can see that scientific language was created through cultural, historical, and institutional settings. Scientists use language in particular ways in order to communicate certain values and epistemologies such as objectivity, rationality, and power. Femininst critiques of science also point out that the relative complexity of scientific language use serves as a barrier to participation, creating an aura of mystery impenetrable to the average person (Harding, 1991). It is no surprise, therefore, that students need support in understanding the very particular uses of scientific language that are important to communicating one’s scientific reasoning.

Furthermore, students come to the classroom with their own ways of making sense of the world through language that might be different from scientific ways of using language. Because teachers might already be familiar with scientific ways of using language, they may not realize how their language use reflects certain beliefs, values, and actions that students are unfamiliar with. Consequently, students may have different interpretations of scientific practices than teachers because they do not understand the subtleties of practice inherent in the language. For example, Rosebery, Warren, and Conant (1992) found that students had limited understandings of constructs such "hypothesis" and "evidence". They found that students had trouble conceptualizing a hypothesis as a statement that could be tested through experimentation. Students conceptualized "evidence" as facts that they "knew" through prior experience, personal knowledge, or secondhand sources. However, in inquiry classrooms, these terms are often used as if they were transparent, without the teacher or curriculum materials supporting students in understanding how "hypotheses" or "evidence" are specialized constructs in science.

Lemke (1990) warns us that because science-specific ways of using language may be unfamiliar to many students, science instruction may perpetuate a "mystique of science" which serves as an obstacle to participation for many students. The creation of this "mystique" stems from the norms of scientific language use that "serve to create a strong contrast between the language of human experience and the language of science" (p. 134). This mystique tends to present science as more difficult to learn than it really is as well as something that is very far removed from students' everyday experiences. We therefore need ways to bridge the gap between the ways in which students use language in their everyday experiences and the ways in which scientists use language in the course of an investigation. As with any curriculum effort in classrooms, the teacher is the key to providing this bridge between students' intuitive uses of language and science-specific uses of language. The question I explore in this section is *how* teachers provide this support.

As I will illustrate in this section, I saw Denise and Sherry bringing in linguistic elements to aid in the enactment of cognitive goals in three ways:

1. defining scientific terms and processes,
2. interpreting representations, and
3. using discourse markers such as "why" to signal norms for action.

I will describe how, by using these strategies, I saw several ways in which teachers could operationalize the multidimensional aspects of inquiry practices in classrooms. I describe each of them in turn below.

Defining new scientific constructs and processes

Cognitive skills such as constructing evidence-based explanations are challenging both because students need to understand not only what actions to take—finding patterns in data, making claims, having evidence to support those claims—but also what it *means* to make a "claim" and have "evidence" in the context of a particular investigation. There are two aspects of understanding scientific terms: understanding the definition of a term, which can often be very specific and different from students' everyday uses of a term, and knowing how to interpret that term in a variety of situations (Reif & Larkin, 1991). The scientific term becomes a marker for a specific concept and often a specific set of steps in an investigation. The challenge for students, therefore, is understanding how to combine the scientific language with the appropriate actions and content. Lemke (1990) argues that part of learning science is learning how to apply scientific terms in multiple, appropriate contexts. However, these terms sometimes hold very specific meanings that may be different from their everyday counterparts. More specifically, scientific language can "technicalize" everyday words and concepts such that the scientific term is condensed: one term can stand for a category of terms or actions (Halliday, 1998).

Another difficulty in understanding how to use scientific language, therefore, comes from understanding what is included and what is excluded in scientific terms that are made technical by science but not in an everyday sense. For example, one way to form an "explanation" in science is to make a claim based on evidence. In its everyday meaning, "explaining" usually refers to "the act of clearing from obscurity and making intelligible" (Merriam-Webster's, 2002). For example, one can explain how to drive a car or explain how to bake a cake. These everyday uses can potentially confuse students and hide the complexity of the scientific practice. Students may not realize, for example, that they need evidence to support their explanations in science because one does not need evidence in everyday explanations. Therefore, supporting cognitive elements of inquiry involves not only supporting an understanding of the linguistic elements used to refer to the practice itself but also modeling how to engage in the complex reasoning required of the practice.

In the following sections I will illustrate how Denise and Sherry supported specific cognitive tasks by defining both scientific categories and inquiry processes. I will use numerous classroom examples to show how their attempts to support inquiry practices such as data interpretation and forming conclusions ranged from very explicit to very subtle and tacit.

Using language to construct new categories for sensemaking

Outside of school and science, concepts can be loosely associated with observations. In our everyday lives, we do not need to specify concepts such as "ATM" precisely because they can be defined through repeated experiences and analogy with a group of similar observable items (Reif & Larkin, 1991). In contrast, concepts in science need to be precisely defined so they can be useful as tools for making predictions, inferences, and explanations of observable phenomena. As I argued above, scientific terms can embody both a scientific concept and a set of methods for data interpretation, making inferences, or forming explanations of phenomena. Science demands that these terms be precisely specified so they can serve as markers for action and markers for specific concepts. For example, in inquiry, students are often asked to interpret complex data that often involves forming categories, based on scientific principles, in which to place patterns that they see in the data. If students are interpreting a graph of fluctuating population levels in an ecosystem, they need to understand when the population is “stable”, when it is “unstable”, when it is decreasing and increasing. These terms stand for a multitude of possibilities that students may see in the data. For example “stable”, which in this case means that a population fluctuates within a steady range, could manifest itself in a variety of situations, including fluctuations within very small and very large ranges. A challenge for an inquiry practice such as data interpretation, therefore, is not only understanding the definition of a category but also applying that category to a variety of situations. In the following example, which comes from Lesson 10 of the unit, Denise defines the terms “stable” and “range” as she helps students with the task of data interpretation:

29 S: Is that kind of stabilized too?
30 T: Does that kind of stabilize? What do you think guys? Does this kind of stabilize from probably the point where the rabbits and stuff die to this? Is that pretty stable?
31 Ss: Yeah.
32 T: Yeah because it’s still going up and down but it’s still within a certain range of things. Do you know what I mean by a range of things? Um, doesn’t go beyond something or below something. Never dies out. And it still goes up and down. And up and down are called fluctuations if you didn’t remember that.

In this example, students are looking at a graph of fluctuating population levels from a computer simulation. They are trying to describe a certain area of the graph but the students are getting confused by the term “stable”. Denise defines the term while she refers to a particular part of the graph on the overhead in line 30. She also defines “range” and “fluctuation”, two more terms that are important for the task of data analysis. These terms are important for students to use them to describe whether populations are fluctuating within a stable range or whether populations are in danger of dying out. As students analyze data from the Great Lakes food web, they use these terms to gauge the effect of the sea lamprey on native fish population levels over time. Students need the terms “stable”, “range”, and “fluctuation” as tools for analysis and a shared understanding of these terms is necessary for them to share their analyses with the class. This is an example of the overlap between the cognitive and linguistic dimensions: the teacher was attempting to accomplish the cognitive goal of data analysis, but this entails having a language with which to categorize parts of the data. Denise explicitly calls them out and thereby gives students tools they can use to engage in the cognitive task.

Sherry supported this practice using much more tacit strategies which put all of the responsibility on the students to infer the appropriate use of the language from the context in which it was used. In the following examples from lesson 9 of the unit, Sherry uses the term “fluctuation” to describe trends in the data from the computer simulation described above. However, she uses the term as if it were transparent to students despite having never defined it.

> 75 Jess: But what happened when we did our variation, the snakes increased, the rabbits at first they increased but then they decreased, and the grass started out good and then it decreased too. It started out increasing and then it decreased.
> 76 Sherry: Ok so basically what we see after 50, 60 generations is that there’s some fluctuations. Some of you guys saw the snakes go up, some of you saw the snakes go down. Right?
> …
> 87 Sherry: So clearly we had some fluctuations, we had different experiences with this model right?
> …
> 102 Sherry: Hold on. What they were saying that they saw was the rabbits and the grass fluctuated…
> 103 Jen: What does that mean?

104 Sherry: Moved up and down. So when rabbits are up, the grass is down.

In this example, Sherry uses the term “fluctuations” first to revoice a student’s description of increasing and decreasing population levels and then to more generally describe a pattern in the data. However, she never clearly defines the term until a student explicitly asks her to. In line 81, students have to infer that “fluctuations” refers to the pattern of data after “50, 60 generations” in the snake population. Then in line 87, Sherry uses the term “fluctuations” before she says “we had different experiences with this model”. From this sentence, a student might infer that fluctuations means “different experiences” rather than a certain pattern in the data. Finally, in line 102, she says that “the rabbits and the grass fluctuated”. This is in contrast to how she used the term in line 81 with just a single population fluctuating.

This tacit use of terms highlights one of the major challenges students may face when they engage in inquiry practices. Students are often immersed in an investigation and expected to engage in particular practices such as data analysis as the need arises, with little direct instruction from the curriculum or teachers on how to do so. In Sherry’s example above, the task of data analysis, which is itself a complex practice, is made more difficult by the complexity of the language used to describe the data. Students need to both infer the meaning of key words such as “fluctuation” and use them in their own analyses. This puts the onus on the students to pick up on subtle cues from the teacher in order to correctly engage in the inquiry practice. This strategy of not explicitly defining terms also caused confusion around the meaning of “stable”. In the following example, Sherry defines the term but does so without explicitly calling attention to it:

Sherry: Did it stay somewhat stable where the lines were pretty much the same….

Students were looking at a graph that traced populations of three species and the lines never “stayed the same”, but they fluctuated at times within a certain range. Therefore, when students tried to apply this definition to their own use of the word “stable”, they were confused and had interactions such as the following:

274 Sherry: Sammy says his, the snakes, invasive species, and grass were pretty stable.
275 Jen: Meaning stable, like was it straight?
276 Sammy: No the lines were going to the same spot.
277 Jen: You mean unstable like increase and then decrease?
278 Sherry: Stable as in you pretty much see similar patterns as it’s going. There are some peaks, there are some declines, but they’re pretty stable.

In the above interaction, Jen has equated “stable” with “straight”, which makes sense from Sherry’s definition of “it pretty much stays the same”. After the interaction between Jen and Sammy, however, Sherry gives a more specific definition of “stable” that allows for “peaks” and “declines” but does not include the idea of fluctuations within a certain range. This example highlights again the importance of language while engaging in a cognitive task such as data analysis. In order to engage in and communicate an analysis of data, there needs to be a common understanding of the language with which to communicate those analyses. Terms like “stable” and “balance”, which were central to this task, needed to be defined more clearly in order for students to apply them as well as understand each others’ analyses.

In these examples, Sherry attempts to support the use of categories such as “stable” and “fluctuations” in very tacit ways. Upon initial observation, one might not describe her practice as “support” since she uses terms without seeming to define them and only defines them when students reach a state of confusion or explicitly demand it. However, I would still describe Sherry’s practice as “support” because she models the use of the technical language. Although this puts the responsibility on the student to infer the meaning of the term, she is using the language in the context of its appropriate use. This modeling consisted of rephrasing students’ language into more technical language, using technical language to ask questions, and defining technical terms as needed (or asked) by students. Sherry’s case highlights one of the major challenges facing students learning inquiry science: they must learn the very specific language of science by subtle cues from the teacher. In the next section I explore the ways in which Denise and Sherry define inquiry processes for students.

Using language to define and model expectations for inquiry processes

In the previous section I described Denise and Sherry's support of scientific categories for sensemaking during the cognitive task of data interpretation. In that task, it was essential for students to come to shared understanding of categories for data interpretation in order to both engage in and communicate the results of the practices. Therefore, Denise and Sherry defined terms and modeled their use in that task, thereby supporting the cognitive task through linguistic supports. Other inquiry practices, such as constructing conclusions from data, necessitate that students use language in specific ways to communicate their findings. Constructing conclusions from data is a complex practice, often involving synthesizing information from several data sources, choosing the most relevant data to use as evidence, and constructing a conclusion based on that evidence. Furthermore, the evidence used in support of a conclusion must be specifically referenced so others can decide for themselves if they believe a particular conclusion.

The act of referencing data can be confusing, especially if students do not understand the scientific norms for doing so. In the following example, Denise explicitly states her expectations for use of evidence as students construct conclusions from data:

309 Denise: Alright so where did you get your data?
310 Eric: The chart
311 Denise: can you just like say, you're going into a real important meeting and you have all this research and say, it's based on my chart, here it is.
312 Ss: Yeah
313 Denise: No, you can't do that! No! You can't say, here's my evidence. You gotta say, specifically on chart number 1, on this line, shows this. You can't just say well here it is, I'm too lazy, I want to go on spring break! [Ss cheer] [T laughs] So. Somebody else.
314 Mike: I put that matings are decided only on the number of spots but not the length of the tail. Because right here on the surviving males, one of the peacocks had a length of

121 but only had 5 matings but the one that had the most matings only had 113 tail but most matings had the most number of spots.

315 Denise: Now see? He gave me evidence. He gave me a conclusion, he gave me some evidence, he went to the chart. Your group gets the A for the day. [clapping]

In this example, Denise has asked the students, in their small groups, to construct conclusions about what factors affected peacocks' survival and chances for mating. Students were to synthesize information from several graphs and charts in order to construct these conclusions. In the beginning of the example above, Eric has just finished sharing his conclusion when Denise asks him to reference the data he used in constructing that conclusion. When Eric says "the chart", Denise uses this opportunity to explicitly model her expectations for referencing data in scientific conclusions. Notice that in modeling this skill, she simultaneously models the language with which to reference data ("specifically on chart number 1, on this line") and the actions needed to complete this skill (going to a chart and referencing specific line numbers on that chart). In line 314, Mike picks up on Denise's cues and is very specific when he references the data on which he based his conclusion. Denise reinforces this in line 315 by putting names to the parts of Mike's response: "conclusion" and "evidence". This is a clear instance of explicit support for the cognitive and linguistic dimensions. Denise was explicit about her expectations for the cognitive skill of constructing conclusions based on evidence, but communication of expectations necessarily involved being clear about the meaning of "conclusion" and "evidence" in this context.

Referencing data in scientific conclusions is necessarily a linguistic and cognitive construct. It is a cognitive construct because it involves reasoning about data and including some data while excluding others for particular reasons. However, it is a linguistic construct because it is through language—used in particular ways—that data are referenced and conclusions are communicated. Denise not only modeled the task of referencing but also referencing to a particular level of specificity. Her expectation was not only that students had evidence in their conclusion but that the evidence be referenced. Students were to not only reference a chart, but a particular *line* in the chart. Denise's example points to the key role language plays—not only in the act of modeling language use but also in the act of being explicit about a practice—in the support of a cognitive task such as referencing data in a scientific conclusion.

Summary

My observation of Denise and Sherry's efforts to define scientific terms and processes highlights the important role that language plays in the cognitive work of science. In the case of defining terms, language becomes key because it is difficult to agree on a particular analysis of data if there is disagreement about the meaning of terms such as "stable" or "fluctuations". The teachers used a variety of strategies for calling attention to and modeling the use of complex scientific language: explicitly defining, using synonyms, and using terms in context. If one imagines these scientific terms as tools with which students can then conduct their analyses, the importance of these types of "defining" discussions becomes clear. Students need to converge upon a shared set of tools so that they may critique or at least understand each others' analyses. Therefore, the intersection of the linguistic and cognitive dimensions seems essential in this practice of data analysis.

In Denise's effort to define the scientific process of referencing data, linguistic elements are important to communication of cognitive work in science. Here the linguistic dimension involves more than simply vocabulary terms: there are certain linguistic conventions for communicating one's results that simultaneously serve to communicate values of reliability and thoroughness. Denise attempted to emphasize scientific linguistic norms for communicating one's results: by referencing specific data points rather than vague data sources, students' results becomes more convincing because they can then be referenced by others. Such linguistic conventions are specific to scientific work and may therefore be unfamiliar and seem unnatural to students. This makes it all the more essential for teachers and curriculum materials to provide support that will bridge students' experiences with language and science-specific ways of using language.

Interpreting representations

Another way in which the cognitive and linguistic dimensions may overlap is with the use of representations. Science is necessarily a multimodal language—that is, the language of science incorporates text, mathematical expressions, and graphical and other visual representations (Lemke, 1998). Students often need domain-specific strategies to interpret and understand the information in representations because in them are embedded the norms and practices of the discipline that created that representation. In learning how to engage in scientific practices, therefore, students need to be fluent not only in constructing and interpreting scientific text but also in constructing and interpreting scientific representations. Roth & McGinn (1998) argue that representations are social constructs that communicate meaning in specific ways, and that it is difficult to understand the relationship between the representation and its referent in nature without understanding the practices of the domain that created that representation. However, representations can be very far removed from the reality of the original study, but are understood to represent that reality nonetheless. They often synthesize various sources of information and illustrate phenomena too complex to be stated in words (Roth & McGinn, 1998).

I argue that in an inquiry investigation, language may be used to connect scientific representations to the scientific ideas and practices that they embody. Representations can be "decoded" into language that may be more accessible to learners. For example, students may intuitively understand that a population will increase if its predator disappears but may be unable to recognize that pattern on a line graph or scatterplot. Understanding representations is key to being able to use data as a basis for making predictions or constructing explanations. Inquiry curricula often have students either creating or at least analyzing many types of representations such as diagrams, graphs, and charts. While the emphasis in an inquiry investigation is not on the mechanics of these representations, understanding the representations is often key to engaging in an inquiry skill such as data analysis.

In this unit, students needed to use three main types of representations to do cognitive work such as making predictions, data analysis, and constructing explanations based on evidence: food webs, graphs (bar graphs, line graphs, and scatter plots), and data charts. Interpreting the meaning of a representation like a line graph involves both cognitive and linguistic elements. In this section, I will describe how Denise and Sherry used language to map between representations and phenomena to help students interpret representations.

Both Denise and Sherry supported the use of representations by interpreting their meanings in a fairly explicit manner, calling attention to the representation at the same time that they decoded the information contained in the representations. In the following example from lesson 9 of the curriculum, Denise helps students interpret a line graph by translating it into words:

133 Mark: Everything’s just going to die for a while.
134 Denise: All at the same time?
135 Mark: No, after a while.
136 Eddy: Everything’s going to slowly die.
137 Denise: Everything will slowly die after a while.
138 Ss: Yeah
139 Denise: And that would be because?
140 S: Not enough food.

141 Denise: Not enough food. So, um, let's see. What happens to the population after…Ok, we're going to add the invasive species here. Let's see. And this is about 50-60 [indicates on overhead]. So, rabbits are in blue, what happened to them?
142 Eric: They just went down.
143 Denise: They went down. Who went down the furthest? The grass is in green here it is right here. Here's the rabbits. Can you see them? It's hard to tell. Can you see them? No?
144 Ss: No
145 Denise: Blues are the rabbits. So at first they went up a little bit and then they went…
146 Ss: Down.
147 Denise: Then they flatlined here. Look at that. What does flatlining mean?
148 Ss: Died
149 Denise: They died, ok?
150 Mark: So did the snakes.
151 Denise: Well, snakes are in orange. Let's follow them. It's hard to tell which is the orange. Here's the orange. They went up, they kind of remained ok for a while, and then they died about here. Ok? The rabbits died much sooner. They died around here.
152 Eddy: What about the grass?
153 Denise: Let's see grass. Grass is green. Actually, grass went down like somebody said they would, um, Corey said they'd go down for a minute. And then it started having just all kinds of fluctuations and guess what? Grass kind of stabilized over here. Look at it. It never died.

In this example, students are trying to understand the relationship between the species (predator, prey) by looking at these population levels on the graph, as shown in Figure 1. However, it is not immediately obvious what one should look at first. One approach might be to trace the population level of one species such as the snake and determine its behavior over time. Denise models this approach in order to use the representation to make predictions about phenomena. In the beginning of the example, Denise asks the students to predict which population will die first. One of the hypotheses on the table, the one Mark contributes, is that everything will die. In line 141 she refers to the representation to see what "really" happened to the populations over time. In so doing, she models how the representation can be used as evidence for a claim or a prediction. In lines 151 and 153 she models how to "read" the graph by calling attention to one line and tracing it over time.

This example points to one way teachers can translate a representation into language that students can understand. By equating the orange and green lines with the snake and grass, Denise decoded information in the graph that can then became useful for making claims about population levels and explaining a chain of events. This may be one way to help students see that the representation contains important information about the populations fluctuating or dying in response to other populations. This is also an example of the power of representations once one has the expertise to interpret them. This particular graph contains complex information about relationships between organisms in an ecosystem and patterns of interactions between those organisms. However, if students lack the expertise to interpret representations according to scientific ideas of, for example, predator/prey relationships, they may fail to understand how these theoretical ideas can play out in concrete situations like the Net LOGO simulation in this lesson.

Another approach to analyzing this representation might be to look at the interaction between species: as one goes up, the other increases, decreases, or stays the same. In the following example—also from Lesson 9 of the unit—Sherry models this approach and helps students use the representation to make predictions about the species interactions over time. The students are looking at the same graph as in the above example.

139 Sherry: Ok so in the second model, the snakes don't really change much?
140 Gary: Not really.
141 Kevin: If you look at it there, it's the same. It's stable.
142 Jen: It goes a little up but it doesn't go too much up like….
143 Sherry: does it stay like this? [puts another overhead up] Can you guys remember? I mean clearly we have in the beginning whoa! A lot of rabbits, snakes start eating them, then we drop them. Right? A lot of rabbits, very little grass…
144 Kevin: It balanced more…
145 Sherry: What?
146 Kevin: It balanced pretty quickly.
147 Sherry: Yeah. Well this is 1200 generations. Does this look about what you guys saw?

148 S: Yeah
149 Sherry: What do you think will happen to the population when the rabbits—grass, rabbits, snakes, if you let the simulation run for 10,000 generations? Gus?
150 Gary: I don't think there'll be a big change.
151 Sherry: Why?
152 Gary: Because it's going to stay, like it's pretty like stable.
153 Sherry: So over the course of time in a food web or chain, what's going to happen to it? Is it going to be changing a lot if we don't change anything in that food web?
154 Jen: It's going to pretty much stay the way it is. It'll stay steady like the 200-1000 generations, that decrease and increase, it'll pretty much stay like that after 10,000 generations.

As in Denise's examples above, Sherry decodes the representation into language

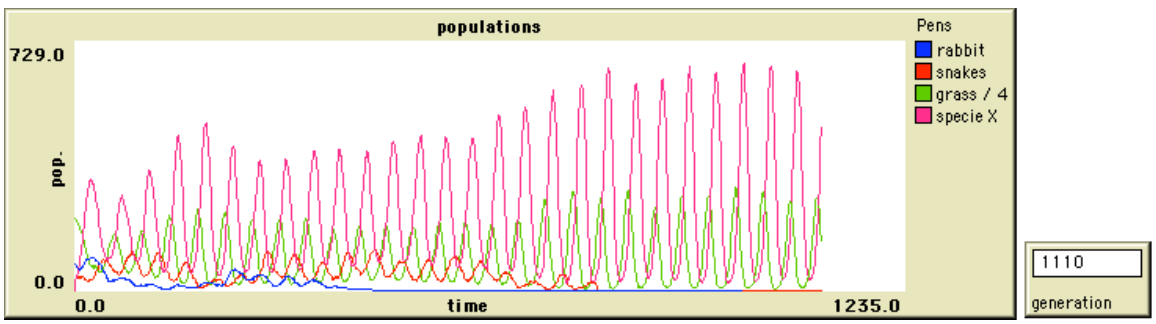


Figure 7: Computer simulation of fluctuating population levels of rabbits, snakes, grass, and invasive species.

that is accessible to students. However, she models a different approach to analyzing the representation. In line 143, she talks through how to read more than one line at once in order to understand how one species affects another. This is important because the graph can seem pretty overwhelming at first glance. There are four lines, all fluctuating at different intervals, and it may be difficult to understand how this representation could show interactions between species. By pointing out specific parts of the graph in which one can see such interactions and "reading" the graph at the same time, Sherry decodes the information in the graph at the same time that she models how to use it to explain a phenomenon. Later in the interaction, when Kevin says "It balanced pretty quickly", she points to the graph as an affirmative example of that "balance". In doing this, she gives a name to the overall pattern in the graph and then asks students to make predictions based on that pattern.

Both Sherry and Denise model how to "read" the data by talking through the trends that students should pay attention to as they point to specific parts of the graph. In Denise's example, she traces the orange line and says "They went up, they kind of remained ok for a while, and then they died about here", indicating to students in words what it means on the graph when a population is "ok for a while" and when it "dies". This is important in understanding what the fluctuations on a single line mean in terms of population levels. In Sherry's example, she models how to read the graph while explaining the trends in the graphs in terms of the interaction between the species. She explains the rapid decline of the rabbit population by saying, "snakes start eating them, then we drop them". Then she explains the low grass population in terms of a high rabbit population at the beginning of the simulation.

Interpreting a representation involves at least two elements. The first is to map the representation onto the phenomenon it is representing. Denise and Sherry do some of this. In Denise's example, she says "snakes are in orange", thereby reminding students that the orange line on the graph is not just a line—it represents a population. In Sherry's example, she speaks exclusively in terms of the phenomenon while she points to the lines on the graph. The second, related element of interpreting a representation is understanding how to "chunk" the representation into usable parts. The teachers could have focused only on the number of generations shown in the graph, or the colors of the lines. What they did, instead, was point to specific chunks of the graph in which interesting things are happening to the population. In Denise's example, she says that "they went up, they kind of remained ok for a while, and then they died about here" while she points to the graph on the overhead. In this way, she not only translates into words what the graph says at particular points, but calls attention to the snake population and when it died. In Sherry's example, she points out the rapid decline in the rabbit population after the snakes started preying on them. By calling attention to this part of the representation, she accomplishes two things: she models how to interpret the representation and also what the representation would look like if a particular interaction occurred between two populations.

Summary

Using representations to make sense of scientific phenomena is a complex practice because representations contain many layers of meaning that students must decode. By "talking through" these representations, the teachers made the cognitive task of data analysis more accessible to students. They put encoded information into words students could understand as they were directly referring to the representations. In this way, they deconstructed the representations into a usable form for students. As I argued before, the focus in the investigation is not to understand the mechanics of the representation or even to understand how to recognize trends in the representation. The focus is on using those trends to understand something about the scientific phenomenon at hand. In this case, students were to use the graph to understand how interactions between species in a food chain could lead to fluctuating population levels. Denise and Sherry supported this cognitive task by modeling how to map from the representation to the phenomenon, pointing out important chunks of the graph, and using the graph to look at species interaction.

This strategy highlights the importance of using language to support cognitive tasks. In this case, representations encode domain-specific information that is often key to understanding scientific phenomena. As I argued at the beginning of this section, representations are often very far removed from their referents in nature. Furthermore, it may be difficult for students to recognize a pattern that makes sense to them intuitively, such as the rabbit population increasing as its predator population decreases. In fact, one of the key features of scientific text is that it includes representations that are understood as if they were text (Lemke, 1998). A series of graphs will tell more than scientists could put into words—about control experiments, experimental conditions, and results (Roth & McGinn, 1998). In order to interpret this type of information, students need specific strategies for approaching representations. Notice that neither of the teachers simply said, "the snakes died when the rabbits died". Instead, they modeled how to use the representations to make sense of phenomena. By supporting students' sensemaking around representations through language, teachers supported this complex cognitive task.

Using discourse markers to signal norms for action

Teachers' support of inquiry practices can range from very explicit to very subtle and tacit. Being able to successfully engage in inquiry science in classrooms therefore depends not only on understanding the language of science in written and represented forms, but also being able to, as Lemke (1990) puts it, "find the science in the dialogue" (p.11). In other words, students and teachers are constantly engaged in dialogue that may or may not contain important information about the task at hand. How do teachers signal to students that certain action is called for, or that they need to attend to a particular task? In this section I explore teachers' use of discourse markers to support students' actions in inquiry tasks.

Studies in discourse analysis and linguistics have argued for the importance of discourse markers in comprehension of spoken language such as everyday conversation (Schiffrin, 2003), lectures (Chaudron & Richards, 1986), and following instructions (Tree, 1999). Discourse markers are either single words or strings of words that signal information to one or more listeners. This information can take many forms, such as using “and” to signal a list of things that all belong to the same category (Schiffrin, 2003). For example, Chaudron and Richards (1986) found that discourse markers such as “on the other hand”, “to begin with”, and “for the moment” serve various functions such as organizing content, connecting topics, indicating topic continuation, and closing a topic. They found that learning to listen for certain types of discourse markers—those that signal major transitions—can help second-language learners process the information in the lecture into categories. Therefore, as students are learning to engage in scientific practices, discourse markers may serve an important role in helping them process and organize information from the teacher.

Furthermore, in classrooms, as in all conversation, dialogue between teachers and students does not occur in a vacuum. Lessons occur within certain activity structures that are jointly negotiated between teachers and students (Lemke, 1990). A classroom lesson often has an opening sequence in which the teacher reviews what was learned the previous day followed by the main lesson, and finally the lesson closes with a review of the day’s lesson, a preview of the next day’s lesson, or a homework assignment. It can often be helpful to students to have markers to call attention to phases of a lesson or activity so they know the appropriate action to take in particular parts of a practice or discussion. Kolodner and Gray (2002) found that “rituals”, or specified activity structures, helped students understand expectations for practices such as designing experiments and participating in poster sessions. These rituals were repeated often throughout an inquiry unit and therefore gave students several opportunities to engage in a practice and seemed to serve as placeholders for a particular set of actions to take.

While we did not have rituals in our curriculum, discourse markers serve much the same purpose: to delineate a practice for students and set up expectations for action. Therefore, students' ability to pick up on discourse markers in Denise and Sherry's classrooms was likely a combination of teachers' repeated use of discourse markers and the norms of the activity structures established in the classroom. These markers were an important way teachers modeled some of the attitudes and values of scientific inquiry. For example, asking "why" after a student makes a claim accomplishes several goals. The first goal is that it signals the need for evidence or reasoning, whatever the norm is in the classroom. The second goal is that it reminds students of the next step of the practice. Finally, the particular marker "why" is a way for teachers to model the skepticism of science: by not taking students' claims without evidence, they model the attitude in science that claims need to be backed up in order to be convincing. In this section I will illustrate Sherry and Denise's use of linguistic markers and how they were an integral part of supporting the cognitive tasks of inquiry.

The first linguistic marker the teachers used was "why". This is, of course, a fairly common question teachers ask students, sometimes accompanied by further specification of what the teacher is looking for, and sometimes not. For example, a teacher could ask, "Why do you think the trout population went down?". In this prompt, the teacher specifies the particular subject of the response she expects. I define the use of the linguistic marker as those times when the teacher uses the prompt alone, without any specification. The students' appropriate response is indicative of the shared understanding of the meaning of that prompt. The following example is from Sherry in Lesson 8 as she asks students to make predictions from a food chain:

52 Sherry: If something happens to the aquatic snails and that population goes, what's going to happen to the algae?
53 Larry: They'll grow
54 Sherry: **Why**?
55 Larry: Because there's less things that will eat it.
56 Sherry: Ok so population grows. We're using arrows to show that it increases, ok? Arrow pointing up. What's going to happen to the chub? Aiden?

57 Aiden: It will die
58 Sherry: **Why**?
59 Aiden: Without the aquatic snails it will die out unless it has another organism it can eat.
60 Sherry: Ok so we're going to assume that just for this food chain, there is no other food source for the chub, ok?

In this example, Sherry has drawn the following food chain on the overhead:

Algae ⟶ aquatic snails ⟶ chub ⟶ lake trout

She asks the students to predict what would happen if the snail population were removed from this food chain. Sherry repeatedly uses the linguistic marker "why" after Larry and Aiden make their predictions. By using this marker, Sherry accomplishes two things. The first is that she signals the need for reasoning to support a prediction, thus both reminding the students of the next step of this practice of making predictions and communicating the "rule" that predictions always need to be backed up by evidence. The second goal Sherry accomplishes with this linguistic marker is modeling the scientific attitude that claims cannot be convincing unless they are backed up by evidence. These two goals are inextricably linked: communicating the rules for a practice necessarily entails modeling scientific attitudes since practices embody the values and norms of science.

The second linguistic marker teachers used was to repeat students' exact words to signal correctness of an answer. This often occurred as the teacher was taking students through a chain of reasoning or trying to co-construct a chain of events with students. The following example comes from Denise as she takes students through the same food chain as in Sharon's example above:

29 S: **Snails are directly affected**.
30 Denise: The **snails are directly affected**. Because what happens to them?
31 S: They die.
32 Denise: Ok. They're dead. What happens then if the snails die and that's the chub's only source of food, what happens to the chub?
33 S: **they'll die too**.

34 Denise: Ok **they'll die too**. What happens to the lake trout then?
35 S: **They might decrease**.
36 Denise: **They might decrease**. Will they die out completely maybe?

In this example, Denise re-states students' exact words to indicate correctness of their responses. Although this looks like a typical IRE (initiation-response-evaluation) interaction, Denise accomplishes important work here. She asks students to make predictions about one species in the food chain, and after she indicates correctness of their answers, she moves on to another species in the food chain. This leads up to an important idea that if one species is removed from a food chain or food web, many species are actually affected. Denise gets to this idea a few lines later when she says

237 T: Ok. So. This food chain, is it dependent on other things in the food chain, or it doesn't really matter.
238 S: yes, it's dependent.
239 T: Ok so we take one thing out, does it affect everything?
240 Ss: Yes

The linguistic marker of re-stating students' words accomplishes two goals. The first is that it indicates to students that their responses are correct. The second is that it allows Denise to give students practice at a skill like making predictions from a food chain without having to be explicit about the rules of the skill itself. Students receive immediate feedback on whether they are participating correctly in the practice without Denise having to explicitly say so.

The use of linguistic markers is an important tool for modeling the skills of inquiry. These markers give teachers a way to support students in engaging in inquiry tasks without having to explicitly state the rules for those tasks. Linguistic markers give students cues for next steps in reasoning and help them understand when they are on the right track.

Summary of the intersection between the cognitive and linguistic dimensions

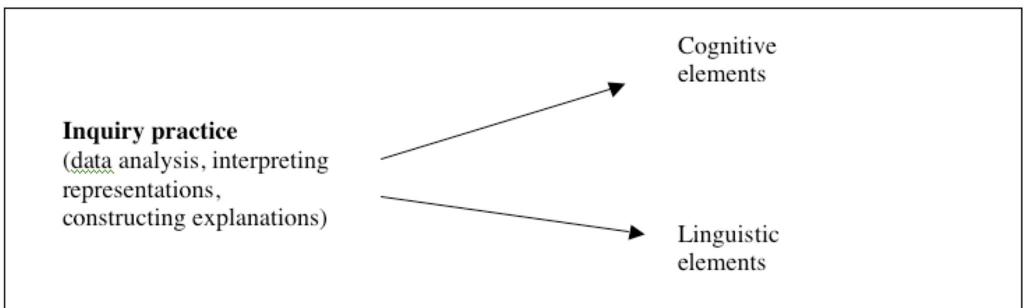
My analysis of the intersection between the cognitive and linguistic dimensions highlights the multidimensional nature of inquiry practices and helps us gain a better understanding of how a teacher might operationalize this multidimensionality in classrooms. Scientific language plays an important role in cognitive tasks not only because there are certain vocabulary words that may be unfamiliar to students, but also because there are certain linguistic conventions that may differ in important ways from linguistic conventions of casual conversations students may have outside the classroom. The instances in which I observed the intersection of the linguistic and cognitive dimensions can lend us some insight into the ways in which scientific language can facilitate the cognitive work students need to do in inquiry.

For example, vocabulary words have science-specific meanings and can become tools for analysis for students. However, students and the teacher needed to first converge on the meanings of these terms in order for these tools to have analytical power. Scientific terms can also stand for categories of ideas, and part of the challenge in engaging in scientific reasoning is applying these terms in productive ways in an analysis. In order to do this, however, students need to understand what is included in a category and what is excluded. Denise and Sherry called attention to these types of terms and using them in the context of an analysis. In this way, they established them as tools for the class to use as they both engaged in the analysis and communicated their analyses to others.

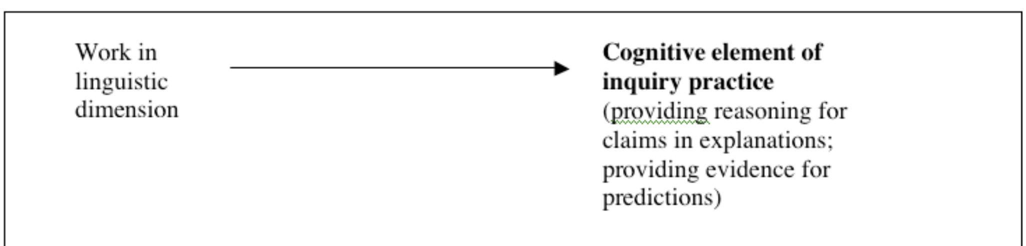
Interpreting representations was another site of intersection between the linguistic and cognitive dimension, and understanding linguistic conventions embedded within representations can enhance the usefulness of those representations during an investigation. Representations contain complex information that is often hidden to the novice scientist. Denise and Sherry used language to accomplish two cognitive goals around representations. The first was to help students map from the representation to its referent. This included, for example, pointing out that an orange line on a graph stands for a certain population. The second cognitive goal was to engage students in the process of analyzing representations. For example, by pointing to certain parts of graph and talking through how to analyze it, they modeled how to analyze a complex representation by first compartmentalizing it into “chunks”.

Finally, because inquiry practices are often complex and unfamiliar to students, another challenge to students might be knowing what order to do things in and if they are on the right track during their investigations. Denise and Sherry’s use of discourse markers points to one way teachers can use language as a tool to help remind students of specific reasoning steps in complex practices. Although this is not an instance of linguistic norms in science, discourse markers point to one way teachers may use language to facilitate students’ cognitive reasoning. In the next section, I explore another case of the intersection of dimensions: that between the social and cognitive dimensions.

These examples all point to concrete ways in which teachers can operationalize inquiry practices in classrooms. In this section, I have illustrated three ways teachers may facilitate the intersection between the cognitive and linguistic dimensions. These are summarized in Table 2. In addition to describing specific ways the teachers were able to simultaneously support multiple dimensions, this analysis also indicates two directions of influence for support of students’ cognitive reasoning through language. The first involves the nature of the scientific practices themselves. In the first two strategies listed in Table 2, pointing to specialized uses of language and translating representations, teachers may have been taking advantage of inherently linguistic elements of scientific practices in order to facilitate the cognitive reasoning involved in data analysis or interpreting representations. For example, because data analysis necessarily requires putting data into categories in order to discern patterns, language is a key element in this practice. Likewise, language is the bridge between representations and the scientific ideas that they embody. Therefore, teachers may take advantage of the multidimensional nature of the scientific practice itself to facilitate important reasoning tasks in inquiry. The second direction of influence is to emphasize the affordances within a particular dimension as a way of shaping students' participation in the practice. In the case of using discourse markers, teachers may use a particular linguistic cue to facilitate students' reasoning in the cognitive dimension of constructing explanations. Therefore, teachers may use more general aspects of the dimensions to achieve reasoning goals for practices. These two approaches are summarized below:



Path 1: Teachers may take advantage of inherently multidimensional aspects of the practice in order to support students' participation in that practice.



Path 2: Teachers emphasize one dimension in order to shape students' participation in inquiry practices.

This distinction between the inherently multidimensional properties of the practice and using one dimension to facilitate work in another may be useful to curriculum designers as they think about how to design domain-specific supports for practices versus more generalized supports for reasoning. The domain-specific supports may come from the nature of the practices themselves—taking advantage of, for example, the inherently social nature of argumentation in order to have students consider multiple explanations for the same phenomena. More general pedagogical strategies, on the other hand, may also emerge from considering the affordances of each dimension and using those to facilitate the reasoning tasks of an inquiry practice.

TABLE 14: Summary of three strategies teachers used to accomplish intersection between cognitive and linguistic dimensions

How teachers accomplished Cognitive/Linguistic overlap	**Purpose**
Specialized uses of language	Creating linguistic categories for data analysis
Translating representations	Using language to understand scientific ideas embedded within representations
Use of discourse markers	Using linguistic markers to signal next steps in inquiry practices

Scaffolding participation in inquiry practices using the social dimension

In the previous section I described strategies Denise and Sherry used as they communicated their expectations for inquiry practices such as making predictions, data interpretation, and drawing conclusions based on evidence. These strategies represented an intersection between the cognitive and linguistic dimensions of inquiry as teachers used language in various ways to facilitate students' work in the cognitive dimension. In this section I describe how teachers attended to the cognitive and social dimensions simultaneously and explore what we can learn from their enactments about operationalizing the social nature of inquiry practices in classrooms.

As I argued in the introduction, scientific practices are inherently social in nature (Longino, 1990; Grene, 1985). Scientists work either collaboratively or in competition with each other to solve complex questions, and the process of peer review serves as a social practice of checks and balances to control the quality of the work that becomes "established" scientific knowledge. Once results are published and made public, scientists build off of each others' results, either elaborating on previous work or trying to refute it. The question remains, however, of which aspects of the social nature of inquiry practices can be imported into classrooms and how teachers might accomplish this.

Inquiry practices in classrooms contain a social element in two respects. First, because inquiry practices mimic in important ways the practices of scientists, students should have opportunities to participate in the social aspect of scientific knowledge construction that scientists also engage in (Driver, Newton, & Osborne, 2000). Second, because these practices are social in nature, this may represent a departure from traditional classroom roles for both teachers and students. Simply opening up opportunities for students to engage in the social aspects of inquiry practices may not be sufficient if students are unfamiliar with the roles they are asked to play. In inquiry, students often take on unconventional roles in classrooms, they have increased responsibility for the direction of their investigations, and they make their ideas public and open to critique (NRC, 1996; NRC, 2000). Teachers cease to be the sole authority in the classroom as students generate their own interpretations of data. Students often need to collaborate on complex investigations into rich datasets in order to explore all possible hypotheses from the data. Within these opportunities to collaborate, there are often norms for collaboration that teachers need to communicate, such as students within a group coming to a consensus before sharing their conclusions with the rest of the class. These roles for students and teachers often differ dramatically from traditional classroom roles in which the teacher lectures or knows all of the answers and the students memorize those answers for a test.

I will explore how teachers operationalized both of these aspects of the social nature of inquiry practices in this section. I describe how the teachers scaffolded the cognitive aspects of inquiry practices by taking advantage of the social elements of inquiry tasks. Reiser (2004) argues that scaffolding entails finding a balance between “providing support and continuing to engage learners actively in the process” (p. 275). In other words, the challenge for teachers in supporting inquiry practices is giving students both the opportunity to engage in practices as well as the guidance to do so. The teachers used three main strategies to scaffold students’ participation in the social aspects of inquiry practices:

1. building a consensus of ideas,
2. co-constructing a chain of reasoning between teachers and students, and
3. sharing responsibility for learning between teachers and students.

I explore each of these in turn in the following sections.

Consensus Building

In inquiry investigations, students are often working with complex representations of rich data sources. These representations often afford multiple interpretations that must be backed up with evidence from the data. For example, when synthesizing data from multiple sources, students may choose to focus on different aspects of the data and therefore form different conclusions depending on the evidence they gather from the data set. In order to advance the learning of the class, the teacher must then pull these ideas together and, based on students’ responses, bring the class to a consensus on the important ideas from the investigation. Consensus can be around one or more ideas depending on the context of the investigation. For example, if a teacher is trying to gauge students’ progress in an investigation, she may have a discussion about students’ conclusions at that point. In this case, she may not be looking for one answer but instead all of the feasible answers so far. At the end of an investigation, however, a teacher may want to converge on a single answer that is most convincing given the available evidence.

In my observations of Denise and Sherry, there seemed to be two steps to this strategy. The first was to hear all possible responses to a phenomenon. For example, teachers might give students time in their groups to formulate conclusions based on data. Then they would pull the class together and have each group share their conclusions. In order to hear all students' responses. The second step was to categorize students' responses in relation to each other. In this way they built the class's knowledge base while acknowledging students' contributions to that knowledge base.

One of the challenges to building consensus in an inquiry practice such as data analysis is that students are often given relative freedom to choose which part of the data they will observe. This often occurs when there is a large data set with several potentially relevant pathways for students to investigate. Furthermore, students are often asked to apply complex ideas to their analyses of data with little to no explicit instruction on how to do so. For example, the idea of "stability" in a population is a complex one to observe in a graph of fluctuating population levels. Therefore, it is often difficult for teachers to anticipate the types of analyses students will construct when they pull the class together for discussion. In order to build consensus around divergent ideas, both Denise and Sherry acted as facilitators of students' ideas: summarizing their ideas, re-stating ideas at opportune times, and situating students' ideas in relation to each other. The importance of the teacher's role as facilitator is highlighted in the following example from Sherry, lesson 9:

120 Belinda: We found that every time the snakes, I mean the rabbits went down, the snakes went down with them because they didn't have enough rabbits to eat. But then when the rabbits, when the rabbits were up, the snakes were up too.
121 Sherry: How many people saw that? Some of you saw that the snakes weren't really affected by the um…
122 Kevin: It was stable the whole time.
123 Sherry: What did you guys think Anna?
124 Anna: It was like um, all about the same, going up and down
125 Sherry: All about the same but up and down? What does that mean?
126 Anna: They were balanced
127 Sherry: How many of you guys saw a balance, that it pretty much stays the same? And now the second issue we have is whether or not when the snake goes up and down [shows the overhead], when the snakes go up, shouldn't the rabbits go down? Right? That's what should happen.

In this example, the students are sharing their observations from the computer simulation shown in Figure 7. There are several important aspects of scaffolding that occur in this interaction. First, Sherry controls the flow of the conversation. Although she asks for multiple observations, she controls when another student shares their observation, and she also asks all of the questions. In this way, she defines her role in this discussion as facilitator of ideas—making sure students' ideas are heard, but periodically restating these ideas to ask for consensus, as she does when she asks "How many people saw that?". In line 122, Sherry brings up ideas from other students as a point of contrast to Belinda's observation. By bringing in another point of view, she facilitates a discussion in which Kevin then shares his observation, one that is also in contrast to Belinda's. Another important feature of this interaction is that in line 128, Sherry pulls out the interaction that is important to notice in the simulation: when the snake population increases, the rabbit population should decrease because the snakes eat the rabbits.

It is often difficult in inquiry to anticipate students' responses in open-ended tasks such as this one. Sherry's interaction illustrates one way in which a teacher can define her and the students' roles such that she retains control of the flow of conversation but still utilizes students' responses to illustrate important content points. Notice that she does not simply field students' responses aimlessly, nor does she stop the discussion after just one student's response. Instead, as students share their observations, she is constantly structuring the discussion. After Belinda's response, she contrasts it with another point of view. After Anna's response, she asks her for clarification and then asks how many other students observed the same thing. She then emphasizes the conclusion that students should walk away with from the computer simulation. This is an example of taking advantage of the social elements of the task: by inviting multiple students to share their observations, she opens up the opportunity for students to participate in the practice of data analysis at the same time that she scaffolds their participation in this practice. By defining her role as facilitator of students' ideas, she ensures that she retains control of the conversation and therefore is able to bring the class to the important point of the task at the end of the discussion. Finally, although the students do not do so, this type of discussion might also open up opportunities for argumentation and debate around different students' analyses.

In the next example, Denise similarly uses the social dimension to facilitate students' reasoning. She summarizes students' responses into a few summary statements and then situates students' ideas in relation to each other. In this example from lesson 14, students were given data from three experiments that manipulated either the length of the peacocks' tails, the number of eyespots, or both. Students needed to synthesize several data sources to form a conclusion about the most important factors to peacocks' reproductive success and survival. This was a complex task in which students needed to first analyze three experimental scenarios, find patterns in the data, and form a conclusion based on the synthesis of those data. Students were given time in their small groups to construct these conclusions, after which Denise pulled the class together for a discussion:

323 Eddy: The chart says for the surviving males, the longer, the number of eyespots, the more it has, they survive. And the less they have, they die.
324 Denise: Ok
325 Eddy: And without them, without the tails, like the less they have, the less chance they have to attract any females because it shows in the chart that the less number of eyespots they had, the less number of matings they had.
326 Denise: Ok. So are you going with this group back here that it's more eyespots and not tail length, or is it a combination of both?
327 Eddy: I think it's both.
328 Denise: you think it's both, you [Mike's group] think it's just eyespots. You guys [Mikes's group] have good arguments, you showed me. And you think it's both based on which one? [flips through the data packet]
329 Eddy: That graph
330 Denise: This one right here. You guys think it's both based on this graph. Ok.
331 Eddy: Probably like the average
332 Denise: Oh, it's kind of like an average? So both have to do with it. Nice job. Good job. Good thing Eddy wrote that. Next time it's going to be one of the others. Go ahead Tony.
333 Tony: We decided that the peacocks with the more eyespots had a better chance of survival. And our evidence is the chart.
334 Denise: Ok, which chart?
335 Tony: on the chart that the dead males had less eyespots and the surviving males had more.
336 Denise: So you're going with eyespots only.
337 Tony: Yes. And tail length.
338 Denise: And tail length.

In this example Denise situates students' conclusions in relation to each other. By doing this, she accomplishes two things. First, she defines the class's knowledge base around this topic. Students in this discussion seem to be falling into three camps in terms of which factor was the most important to a peacock's survival: tail length, number of eyespots, or both. As students share their conclusions, Denise categorizes their conclusions into one of these camps. She asks Eddy, "So are you going with this group back here that it's more eyespots and not tail length, or is it a combination of both?". Denise scaffolds this practice by giving Eddy options of which camp his conclusion might fall in to. The second thing Denise accomplishes with this strategy is acknowledging and valuing students' contributions to the class's knowledge base. By saying, "You think it's both, you [Mike's group] think it's just eyespots.", she publicly acknowledges the value of both Eddy's and Mike's contributions to the discussion. She puts their positions in contrast to each other and calls them out as real positions around an issue. Similar to Sherry's example, she positions students' ideas in contrast to each other, thereby facilitating students' understanding of the complexity of this issue. There is no "correct" answer—there can be several possibilities based on the evidence referenced. Finally, Denise summarizes students' conclusions into simple, summary statements that reflect the camp they fall in to. In line 336, after Tony shares his conclusion, Denise says, "So you're going with eyespots only". In this line she simultaneously summarizes Tony's conclusion into a succinct statement and also positions him in the "eyespots only" camp.

This type of scaffolding is important in whole-class discussions where students are sharing the results of their analyses because students may need support in situating their own results in relationship to others'. Although students may see their role in the discussion as simply sharing their ideas, the scaffolding that Denise does in this discussion suggests that she expects students to be considering how their own analyses agree or disagree with the analyses of the other groups in the class. In this way, whole-class discussions are not just about listening to all students' analyses: instead, they evolve into knowledge-constructing discussions in which important ideas emerge as a result of students' analyses. In order for this to happen, however, the teacher needs to attend to both the cognitive aspect of the data analysis task as well as the social aspect of coming to consensus around the important ideas from the discussion. Denise plays an important role in facilitating this intersection of dimensions.

The two examples in this section highlight the importance of the teachers' role as facilitator of students' ideas. In both examples, teachers used contrasting ideas that came from the students themselves to define the knowledge base of the class and to position students in different camps. Because open-ended tasks in inquiry often result in students forming different conclusions from data, a teacher may want to have multiple perspectives on the table during a discussion. However, students cannot possibly pursue every possible perspective. In the above examples, we saw one way in which teachers could take advantage of the diversity of students' perspectives to highlight the most important and relevant ideas in the task. They first elicited responses to get an idea of the possibilities out there and as patterns emerged in these responses, the teachers began to organize and categorize them. The teachers took advantage of students' divergent views to pull out important ideas in the task and either mapped or contrasted students' responses with these ideas. In this way, students can come to understand how their own ideas fit into the take-away points of the task. This is an example of how the social and cognitive dimensions of inquiry can intersect: as students participate in the practice of communicating either their observations or their conclusions, teachers use their ideas to advance the learning of the class. The ideas are valued not only because they come from students but also because they represent valid and important positions around challenging intellectual issues.

Another important reason why defining the knowledge base of the class is so important is to make discussions more productive. One can imagine a discussion in which every student was free to share his or her idea without paying attention to each others' responses. This is not an uncommon occurrence in classrooms. While this type of discussion may serve to make students feel as if their contributions are valued, it does not advance the knowledge-building of the class. Students may think they are all in agreement when, in fact, they are not. The intersection of the cognitive and social dimensions in consensus-building is key to not only inviting participation in a practice but also addressing complex reasoning and content goals as well.

Co-construction of a narrative

In inquiry, students are often asked to explain complex phenomena based on experiments and data they collect and analyze. Often, complete explanations of phenomena entail a chain of events, parts of which may be distributed in different students' explanations. For example, in the *Survive* unit, students used a computer simulation to understand interactions between species by observing fluctuating population levels. This is a complex practice because there are potentially many things to look at at one time. As one can see in Figure 7, there are multiple species represented in the graph. Furthermore, in the computer simulation, the graph is dynamic—as time goes on, students can see the population levels change. However, because all of the populations are changing in response to each other, students obviously cannot carefully observe all of them at once. Therefore, different students may observe different parts of the representation during the simulation.

Denise and Sherry acted, again, as facilitators of students' ideas in order to construct a "complete" chain of events from multiple students' responses. Instead of simply telling students what happened, however, Denise and Sherry asked a series of questions that, together with students' responses to those questions, culminated in a complete narrative. Upon initial observation, these interactions looked like typical IRE interactions in which a teacher initiates a question, the student responds, and the teacher evaluates. When studied more carefully, however, one can see that the teachers were using the IRE interactions to facilitate important knowledge-building in these interactions. They elicited and used students' responses to their questions as the basis to co-construct a complete narrative or description of a phenomenon.

In the following example, Sherry has brought the class together after the computer simulation shown in Figure 1 to share their observations. The class is going through a worksheet to answer questions about specific aspects of the simulation. The point of the simulation was not to understand how to interpret the representations but to use their interpretations to understand how the species interacted with each other.

36 Sherry: Ok. So what happened?
37 Sammy: It went up real high at first and then it came back down and then it stayed the same all the way down.
38 Sherry: So we see a recurring thing right, we've heard this on all these answers. It peaks and then drops.
39 Sherry: So we peaks, we see the valleys, we see the peaks, and they start getting smaller, correct, and then they sort of stabilize. There are still peaks and valleys and that comes because as the population of rabbits increases, what happens to the grass?
40 S: Decrease
41 Sherry: Decreases. Does the grass completely die out?
42 Ss: No
43 Sherry: Why not?
44 Mary: Because once rabbits eat in one certain area, they eat it all and then they go to another area. And while they're eating in that area, the grass regrows, and then they go back to the same area.
45 Sherry: They move where the food is, right?

In this example, Sherry does several things to build a narrative of what happened. Students were beginning to share their observations about the computer simulation shown in Figure 7. After Sammy shares his observation, Sherry stops to connect his response to what students have seen in other examples when she says, "So we see a recurring thing right, we've heard this on all these answers. It peaks and then drops". In this way she makes use of the social and cognitive dimensions of inquiry. She uses students' responses to model an important aspect of the practice of data analysis: connecting trends across time and place to form generalizations.

Sherry then introduces two important aspects of the simulation. First, she explains that as the simulation proceeds, the fluctuations "start getting smaller, correct, and then they sort of stabilize". Here she is pointing out a subtlety in the graphs that students may not have noticed—that the fluctuations eventually stabilize into a pattern. She then shifts the direction of the discussion by introducing a possible explanation for this pattern when she asks, "There are still peaks and valleys and that comes because as the population of rabbits increases, what happens to the grass?". This move is important because it guides students' observations of the data in two ways. First, it shifts them from simply describing the patterns in the graphs to attempting to find an explanation for these patterns. Second, it signals that the way to interpret these graphs is to look at the interaction between the species—as the rabbits increase, this may have effects on the grass population. She then asks two more known-answer questions in lines 41 and 43 in order to elicit a complete explanation for the patterns in the graphs. This explanation is finally given by Mary in line 44 when she says

> once rabbits eat in one certain area, they eat it all and then they go to another area. And while they're eating in that area, the grass regrows, and then they go back to the same area.

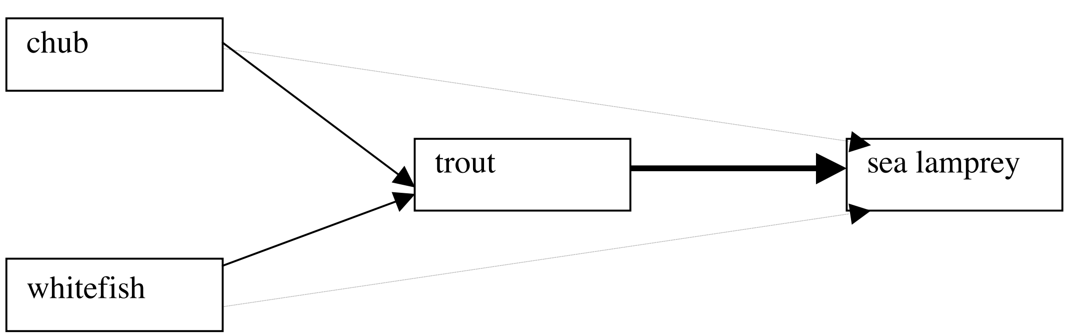
In this response, Mary ties together the ideas of the interaction between the grass and rabbits and the grass re-growing after a period of time. At the end of this interaction, therefore, Sherry has accomplished important cognitive work through her use of the social elements of this task: she has used her guiding questions to support students in explaining the patterns in the graph.

Co-construction involves both the social and cognitive dimensions because the teacher uses students' answers to build a description of the data. Although this may not be as student-directed as many reform descriptions of exemplary inquiry teaching (NRC, 1996), Sherry is nevertheless attempting to engage students in complex reasoning. In this case, Sherry is not using her questions to test the students' knowledge of the data or how well they understand the patterns in the data. Instead, she seems to be helping students—through her questions—build a complex description of the data. I refer here to Wertsch (1991), in his discussion Vygotsky's influence on his sociocultural theory of mind and action, as he explores the social nature of mental functioning. Here he uses an example of a 6-year-old child who has lost his toy and asks his father for help in finding it. The father asks the child a series of questions to help the child remember where she might have left the toy—in your room? Outside? Next door? Finally, the father asks “in the car?” to which the child says “I think so” and finds her toy. Wertsch writes

> In such cases one cannot answer the question “Who did the remembering?” by pointing to either one person or another. Instead, it is the dyad as a system that has carried out the function of remembering on the intermental plane. This same general point has been made in connection to other aspects of mental functioning, such as problem solving. (p. 28)

I apply this same notion to Sherry’s example above. Although Sherry retains control of the conversation, she asks a series of guiding questions that eventually leads Mary to put together a complete chain of reasoning. We can infer from this interaction that the students may not have been able to construct the entire chain of reasoning on their own without scaffolding from Sherry. With her questions, however, the teacher and students form a sort of “dyad” in which students are able to connect the pieces of the chain in a way that might not have been possible on their own.

In the next example, there is another instance in which the teacher uses questioning to elicit complex responses from students. Denise co-constructs a prediction with her students around what would happen to the chub with the introduction of the sea lamprey in the Great Lakes ecosystem. Students are using a food web model as the basis for their predictions and specifically working with the following food chain:



In this food chain, the trout preys on the chub and whitefish and the sea lamprey preys on the trout. However, if the trout population gets low enough, the sea lamprey will then prey on the chub and whitefish. In the next example, students were making predictions about the effect of the sea lamprey on the chub before analyzing actual data that traced the actual effect of the sea lamprey on the chub, whitefish, and trout populations in the Great Lakes.

119 Denise: Ok. Now let's think about it. When the sea lamprey comes in, it likes the trout so you think that will go down.
120 Denise: Ok? So if one of its—if one of the trout's food is the chub, what's going to happen to them at first?
121 Larry: Go up
122 Denise: It's going to go up because?
123 Eddy: There are no predators.
124 Denise: There's no—one of its—
125 Larry: Less predators—for the moment
126 Denise: less predators, they're going to go up for the moment, for the moment they're going to go up and then what's going to happen?
127 S: Sea lamprey eats it
128 Denise: Well then the sea lamprey gets done with the lake trout. Now are we talking you know, days here, are we talking years?
129 Ss: Years
130 Denise: Years. Ok. We're talking long periods of time. We're not talking, you know, this week it ate the lake trout, next week it ate that. No, we're talking years that this happened. And it happened slowly. It didn't happen all at once. Ok. So, what are we going to say about the chubs at first? For a moment it went?
131 Eddy: It went up
132 Denise: and then it?
133 S: Went down
134 Denise: And what's our evidence?
135 Eddy: The sea lamprey finished hunting the trout.
136 Denise: Ok but for the moment it went up because one of its predators was…
137 Eddy: was gone
138 Denise: was gone. And then the sea lamprey turned on it. Ok.

In this example, Denise carefully guides students' responses in order to co-construct a prediction. She asks the students what might happen to the chub, but even this initial question is guided. In line 120, she first states “if one of the trout’s food is the chub”, calling attention to the relationship between the chub and the trout. This signals to the students that they need to pay attention to this relationship when considering the effect of the sea lamprey on the chub population. Second, she says, “what’s going to happen to them *at first*?”, signaling to students that there is an initial effect and then a secondary effect after some time. Therefore, even in the way she initially asks the question, Denise is carefully guiding students’ thinking about this phenomenon.

Denise uses several other strategies to guide students’ construction of a prediction in this interaction. After Larry makes his claim in line 122, Denise asks a question that probes for the reason behind his claim, signaling that an appropriate prediction needs to be backed up with reasoning. She then uses students’ exact words to validate their contributions in the construction of this prediction. In line 125, Larry says, “Less predators—for the moment”, and Denise picks up on this language in the next line when she says, “less predators, they’re going to go up *for the moment”*. She uses this strategy again in lines 136 and 138 as she states a prediction that is the culmination of the students’ responses in this interaction. Finally, Denise elaborates on a student’s comment in order to highlight an important point. In the following interaction,

126 Denise: less predators, they’re going to go up for the moment, for the moment they’re going to go up and then what’s going to happen?
127 S: Sea lamprey eats it
128 Denise: Well then the sea lamprey gets done with the lake trout.

Denise highlights the point that at first the chub population will increase and then it will decrease once the sea lamprey has decimated the trout population. When a student says “sea lamprey eats it”, Denise elaborates on this and says, “then the sea lamprey gets done with the lake trout”. Notice that in this interaction, students would have probably given her a simple prediction such as, “the chub population would increase”, simply based on the food chain shown above. However, with her guiding questions, she is able to co-construct a chain of events with the students that resulted in a multi-step, complex prediction.

In these examples, Denise and Sherry attempt to support students’ enagagement with complex ideas. While it may have been out of the reach of any one student to construct a complete explanation or description of a phenomenon, the teachers opened up opportunities to engage students in the construction of descriptions but then guided their participation in this practice with their questions. This again represents an overlap between the cognitive and social dimensions because as teachers gave students the opportunity to engage in the inquiry practice, they used interactions between students to build an observation or prediction. This represents a departure from traditional roles in classrooms in which students are individually accountable for complete answers to questions. In contrast, these examples illustrate how responsibility for learning can be distributed among many students in the classroom.

Shared responsibility for learning

Inquiry involves both the learning of complex content and the development of skills to generate one’s own scientific knowledge by asking questions, designing experiments, and collecting and analyzing data (NRC, 2000). In order to develop such skills, inquiry requires students to take on more responsibility for their own learning than they might in a traditional classroom setting. On the teacher’s part, this might involve having students design their own experiments, making students’ work accountable to others, or giving students the authority to tackle challenging intellectual issues (Engle & Conant, 2002). This shifting of responsibility from teacher to student represents a dramatic departure from traditional school roles. Therefore, it represents a site that needs some attention from teachers. Both Sherry and Denise used several strategies to distribute the responsibility for learning between teacher and students. Sharing responsibility, however, can be a complex practice to implement in a classroom. Students may not be willing to take on that responsibility, or they may not be used to valuing other students' contributions on the same level as the teacher's. In this section I will describe how Denise and Sherry attempted to scaffold the sharing of responsibility for learning in the classroom by both opening up space in the discussion for students to participate and valuing that participation as important to the knowledge-building of the class as a whole. In this way, they seemed to shift the social situation in the classroom to give students opportunities to engage in important reasoning tasks.

As I argued earlier, referencing data when constructing a conclusion is not a trivial task. Students often do not see the need to be specific about evidence that they cite, if they cite any evidence at all. In the following example, I re-visit an earlier interaction from Denise's enactment of lesson 14 in order to illustrate how she takes advantage of students' responses and guide students' participation in this practice of citing evidence to back up a conclusion:

293 Denise: Oh, Jeremy's ready back here. C'mon, everybody pay attention to Jeremy. Shh.
294 Jeremy[inaudible]…to attract more mates.
295 Denise: Ok
296 Jeremy: It's proven in the chart.
297 Denise: It's proven in the chart by the data ok. So the point of the tails is just to attract males. It's proven by the collection of the data. Ok. I'll take—that's ok.
298 Matt: Ok so we're done.
299 Denise: No you're not. I want more. The next group has to give me more. Eric. Who's going? Eric's going?
300 Eric: The more eyespots a peacock has, the better chance of survival against a predator and a better of getting a mate.
301 Denise: Ok and how do you know that?
302 Eric: it shows it
303 Matt: Better chances…
304 S: Did you see that video where the tiger was chasing it? That helped it—if you die…
305 Eric: Yeah but like

306 Denise: Wait a minute, maybe he has an argument
307 Eric: The ones with less eyespots were the ones that died.
308 Denise: Ok. Maybe that was one with less eyespots. It died…We didn't count the eyespots on that one. Alright…so where did you get your data?
309 Eric: The chart
310 Denise: Can you just like say, you're going into a real important meeting and you have all this research and say, it's based on my chart, here it is.
311 Ss: Yeah
312 Denise: No, you can't do that! No! You can't say, here's my evidence. You gotta say, specifically on chart number 1, on this line, shows this. You can't just say well here it is, I'm too lazy, I want to go on spring break! [Ss cheer] [T laughs] So. Somebody else.
313 Mike: I put that matings are decided only on the number of spots but not the length of the tail. Because right here on the surviving males, one of the peacocks had a length of 121 but only had 5 matings but the one that had the most matings only had 113 tail but most matings had the most number of spots.
314 Denise: Now see? He gave me evidence. He gave me a conclusion, he gave me some evidence, he went to the chart. Your group gets the A for the day. [clapping] Jeremy they did ok because they had to go first and that's the toughest spot to be in.

In this example, Denise uses several strategies to open up opportunities for students to engage in the practice of constructing and sharing conclusions based on evidence. First, she gives students the floor as they get ready to either share or offer arguments. She says, "everybody pay attention to Jeremy" and then she restates his response so that everybody can hear it. In line 306, Denise says, "wait a minute, maybe he has an argument", thereby clearing the floor for Eric's argument to be heard. In both of these instances, Denise marks the importance of both students' contributions to the discussion at the same time as she invites them to engage in the inquiry practice.

Another strategy Denise uses to distribute responsibility for learning is to ask for multiple students to share their conclusions. Earlier in this section I described ways in which teachers elicited multiple responses to get an idea of all possible responses to a phenomenon. In this case, there is a different use of this strategy. What Denise accomplishes here is to use multiple examples to illustrate the norms for the practice. After Jeremy shares his conclusion and says that his evidence comes from "the chart", Matt says, "Ok so we're done." To this Denise responds, "No you're not. I want more. The next group has to give me more." In this way she communicates her expectation that through multiple groups sharing their conclusions, she expects them to build on each other and give her "more". After Eric states that his evidence also comes from "the chart", Denise uses this opportunity to explicitly define the norms for this practice in line 312. In line 313 that Mike picks up on Denise's expectations and is more specific about how he references data in his response. Notice, however, that this comes after two responses from students that did not meet Denise's expectations for this practice. These examples, coupled with Denise's explanation in line 312, seemed to help Mike form an appropriate conclusion.

This example illustrates how a teacher can use the social elements of inquiry to afford opportunities for students to engage in a practice at the same time that she guides students' participation in that practice. She first established the importance of students' participation in this practice by clearing the floor for students as they shared their conclusions, thus she opening up the space for students to engage in the practice and communicating the value of students' responses in this discussion. Then instead of simply telling students how to participate in the practice of constructing conclusions from evidence, Denise encouraged multiple students to share their conclusions and used students' responses to illustrate her expectations for the practice. By building her expectations for the practice off of students' responses in this way, she forced students to pay attention to each other so they could avoid the mistakes of previous students and fashion their own appropriate responses. In the process, she let the need for explaining her expectations for the practice emerge from students' responses.

Another challenge to sharing responsibility for learning in inquiry is the need to understand certain scientific principles in the course of an investigation. For example, as we saw in the previous section, students had trouble understanding the term "stable" in the context of interpreting data in a graph. In such situations, teachers may be seen as the authority, the one with all of the answers. However, Denise and Sherry used a *deflecting* strategy to share the responsibility for understanding these concepts with the students. The following are examples of this strategy:

Example 1:

28 Denise: Alright. Let's talk about when uh, in the next situation when you added the invasive species. [Puts up overhead from Net LOGO showing invasive species graph]
29 S: Is that kind of stabilized too?
30 Denise: Does this kind of stabilize? What do you think guys? Does this kind of stabilize from probably the point where the rabbits and stuff die to this? Is that pretty stable?
31 Ss: Yeah
32 Denise: Yeah. Because it's still going up and down but it's still within a certain range of things.

Example 2:

158 Ally: So whatever eats the lake trout, that population will go down?
159 Sherry: What do you think? If there was a decrease in the lake trout population, what do you think is going to happen?
160 Ally: Yes, it's going to go down.
161 Sherry: And why would that go down?
162 Ally: Because they have less lake trout to eat.
163 Sherry: Right. And then on down the line.

Example 3:

214 Sherry: Because the yellow perch is not eating the lake herring? Do you get it or are you just going oh yeah sure.
215 Sherry: Who gets this? Great, who wants to explain it?
216 S: What's the question?
217 Sherry: Gary will explain it

218 Gary: She said if lake whitefish was wiped out, would it be direct or indirect effect on yellow perch? It would be direct because it's right next to it.

In the above examples, the teachers deflected the responsibility for learning on to the students. In Example 1, students are looking at a graph of population levels of certain fish in the Great Lakes. They are trying to define certain parts of the graph as "stable", "unstable", "decreasing", or "increasing". When a student asks Denise if a certain part of the graph is stable, she says, "Does this kind of stabilize? What do you think guys? Does this kind of stabilize from probably the point where the rabbits and stuff die to this? Is that pretty stable?". In this example, she accomplishes two things. First, she communicates to students that they have the responsibility to articulate their own ideas about this complex concept. Second, she scaffolds this practice by pointing to a specific part of the graph in reference to the term "stable" and thereby constrains the area of the graph in which to apply the term "stable".

In Example 2, students are making predictions from a food web model about what would happen if the population of lake trout decreased in the Great Lakes. Ally asks, "So whatever eats the lake trout, that population will go down?" to which Sherry responds, "What do you think?". In this way, she forces Ally to articulate her own ideas about the interaction between the lake trout and its predators. However, she re-states the scenario for Ally, thereby clarifying Ally's original question and possibly making it easier for her to answer it for herself. Finally, she pushes Ally to articulate the reason for her response in line 161. In this interaction, Sherry both provides the opportunity for Ally to engage in the practice of making predictions and supported her in providing evidence for her prediction through her guiding questions. By pushing Ally to articulate an answer to her own question, Sherry put the responsibility on to Ally instead of herself. Notice that she either could have directly answered Ally's question in line 159, or she could have provided Ally with reasoning in line 161. Instead, she deflected this responsibility onto Ally by asking her specific questions.

Finally, in Example 3, students are trying to understand if certain species in the food chain are directly or indirectly affected by a change in the food web. This is a complex concept because it involves understanding that in a food web, animals are on multiple food chains at one time, and that food chains are linked together in a food web. Students in Sherry's class had difficulty understanding this concept. After a frustrating couple of exchanges in which Sherry was unable to communicate a definition of "direct" effect in a way that students could understand, she says, "Who gets this? Great, who wants to explain it?". In this way, she takes the responsibility off of herself for explaining the concept, hoping that students can communicate to each other in a way they can more readily understand.

Another challenge to sharing responsibility for learning in inquiry is the perceived role of the teacher to control the flow of the discussion. Therefore, students often make comments to the teacher instead of to each other. Because of this, it can be difficult to foster discussion between students about complex ideas. Denise and Sherry openly acknowledged students' contributions to the discussion as a way of sharing responsibility for the progression of ideas. In the following example, Denise is wrapping up a discussion in which students made predictions about the effects of making changing to a food web:

33 Larry: If you take anything out or add anything, everything dies.
34 Denise: Ok. Now did you hear what he said? Larry said if you take anything out or add something, everything eventually dies.
35 Matt: That's what I said.
36 Denise: I didn't hear you.
37 Matt: I said everything eventually dies.
38 T: It may take a while but eventually…

In this example, Larry makes an observation that generalizes all of the predictions from the class's discussion: "If you take anything out or add anything, everything dies". Denise calls attention to this comment and acknowledges that the idea came from Larry. In this way, she puts a value on Larry's comment, value that Matt also wants credit for in line 328. We can see from this exchange that students pay attention to and put value on other students' comments that teachers call attention to.

In the following example, Sherry calls attention to a students' comment and thereby facilitates an exchange between two students:

264 Sam: The lines were balanced. That's why I thought the snakes were eating the invasive species.
265 Sherry: Ok. All the invasive species, the grass, and the snakes were all balanced.
266 Kevin: If there's nothing for that to, if there's no more rabbits, it's eventually going to either eat itself or eat the invasive species.
267 Sherry: The snake?
268 Kevin: Yeah
269 Sherry: Ok. Or it's going to die out.
270 Jen: I don't understand the question.
271 Sherry: What.
272 Jen: They're talking about um, they're saying that the population of the snakes and the invasive species are stable?
273 Sherry: Sam says his, the snakes, invasive species, and grass were pretty stable.
274 Jen: Meaning stable, like was it straight?
275 Sam: No the lines were going to the same spot.
276 Jen: You mean unstable like increase and then decrease?
277 Sherry: Stable as in you pretty much see similar patterns as it's going.

In this example, both Sam and Kevin share their observations about the "stability" of the snake population in the computer simulation shown in Figure 1. Jen, however, is confused about the meaning of the term "stable" and asks Sherry what they mean when she asks, "They're talking about um, they're saying that the population of the snakes and the invasive species are stable?", directing her question to Sherry instead of to Sam and Kevin. Sherry acknowledges Sam's answer once again and thereby facilitates an exchange between Jen and Sam in lines 274-276. In this way, Sherry shares the responsibility for learning with her students by not answering Jen's question directly but instead points to another students' answer as a way to facilitate discussion of this complex idea.

Sharing responsibility for learning represents an intersection between the cognitive and social dimensions. As we have seen in the examples in this section, participation in cognitive tasks such as making predictions and analyzing data may mean re-defining roles of both teachers and students. Denise and Sherry used social interactions such as giving students the floor, deflecting, and acknowledging students' contributions to push students to articulate their own ideas and, possibly, construct their own knowledge around complex ideas. In this way, the teachers invited students to participate in inquiry practices but still scaffolded their participation in various ways such as pointing to relevant parts of a graph and asking guiding questions.

Summary

The intersection of the social and cognitive dimensions that I described in this section highlights some concrete ways that teachers might use social interactions to facilitate students' reasoning about scientific ideas. The strategies teachers used are summarized in Table 3. As we saw in the cognitive/linguistic intersection, my analysis uncovered two pathways of influence teachers might use to simultaneously support the cognitive and social dimensions. In the first case of building consensus, teachers can take advantage of the social nature of inquiry practices themselves in order to facilitate students' reasoning about scientific ideas. By using the whole-class discussion as a forum in which students could not only share their ideas but compare and contrast them with others', the teachers engaged students in the social nature of scientific knowledge construction. By having grouping students' responses into categories of arguments, the teachers were essentially helping to facilitate a community of “scientists” in which different viewpoints were put on the table for consideration. Although we did not see the teachers take this a step further and facilitate argumentation and debate around these different viewpoints, I believe this to be a starting point for such an opportunity.

The other direction of influence—using the social dimension to shape students’ participation in the cognitive aspects of the practice—was evident in the second two strategies listed in Table 3. As the teachers co-constructed chains of reasoning with students and shared responsibility for learning, they were using the opportunities afforded by the social dimension to open up opportunities for students to engage in the cognitive aspects of the inquiry practices. I speculated that through these interactions, teachers scaffolded students into building complex chains of reasoning that otherwise might not have been possible. In this way, the knowledge construction was social in that it was a joint effort between the teacher and students.

TABLE 15: Summary of three strategies teachers used to accomplish intersection between cognitive and social dimensions

How teachers accomplished Cognitive/Social overlap	**Purpose**
Building consensus	Building knowledge base from which to agree or disagree about ideas
Co-constructing chain of reasoning	Using questions to guide co-construction of reasoning between teacher and students
Sharing responsibility for learning	Putting students in roles where they take responsibility for the class’s learning

My analysis from the perspective of social and cognitive dimensions allows us to see several ways in which teachers may bring in the authentic nature of scientific practices while simultaneously scaffolding students’ participation in those practices. This is an important step towards understanding who teachers might facilitate what Aikenhead (1996) calls “border crossing" into the culture of science. Although we did not see perhaps the fullest potential of the inquiry practices being realized in Denise and Sherry's enactments, I argue that these may be first steps to helping students understand the norms across multiple dimensions for participating in scientific inquiry practices.

DISCUSSION

The focus of this study was to explore the ways that teachers might operationalize the multidimensional nature of inquiry practices in classrooms. Given that scientific practices involve social and linguistic as well as cognitive dimensions and that inquiry practices mimic these practices in important ways, in what ways might teachers attend to multiple dimensions simultaneously in order to give students opportunities to, for example, engage in the social practice of scientific knowledge construction? What might this look like in classrooms? In order to answer this question, I looked at instances in which teachers seemed to be supporting multiple dimensions simultaneously. I called these instances examples of the intersection of inquiry dimensions and asked what teachers were accomplishing by this intersection. I explored two instances of intersection: the cognitive/linguistic intersection and the cognitive/social intersection.

This study built on my previous findings that when teachers support inquiry practices, they attend to at least three dimensions: cognitive, social, and linguistic. I took the perspective of inquiry science as a culture in order to highlight the need for teachers to support students not only in learning important scientific content but also in learning how to engage in complex scientific practices that are imbued with the values and traditions of science and scientists. Although educators and researchers have argued for the importance of individual dimensions in enacting and engaging in inquiry practices (NRC, 2000; Crawford, Kelly, & Brown, 2000;

Lemke, 1996; Greeno, 1998), I explored in this study the possibility of teachers attending to multiple dimensions simultaneously through the intersection of cognitive, social, and linguistic dimensions. Inquiry is therefore not only a collection of reasoning tasks for students to engage in. Instead, specific ways of using language and specific types of social interactions facilitate reasoning tasks and help students participate in scientific processes at the same time that they learn complex content. My findings that Denise and Sherry used the linguistic and social dimensions to accomplish work in the cognitive dimension helps us better understand the nature of inquiry practices themselves, the challenge of supporting inquiry practices in classrooms, and the challenges facing students as they learn how to engage in scientific inquiry practices.

This work builds on previous research that outlines general guidelines for "exemplary" science teaching but few details on how to achieve this in day-to-day classroom interactions. For example, Beeth and Hewson (1999), in studying Sister Gertrude's science classroom, outlined several learning goals that the teacher had for students and specified the ways in which Sister Gertrude was able to achieve those goals. However, this was a special case of one teacher who was able to build relationships with students (and have students build relationships with each other) from grades K-5. My study attempts to describe what it takes, in urban classrooms under very different instructional conditions, to put these practices in place.

Multidimensional nature of inquiry science practices

My finding that the teachers in this study attended to multiple dimensions simultaneously adds to existing literature from both the philosophy of science and sociolinguistic perspectives. I argue that the intersection of dimensions I found teachers doing in this study reflects the multidimensional nature of the practices themselves and gives us some insight into how, for example, the social nature of inquiry practices can be operationalized in real classroom settings.

In this section I discuss how this analytical framework that describes inquiry practices as having aspects of cognitive, social, and linguistic dimensions was able to capture some of the complexity of inquiry practices themselves.

This analysis of the intersection of the linguistic and cognitive dimensions adds to existing literature from the sociolinguistic perspective that describes ways in which language can be used as a mediational means with which to accomplish cognitive work (Wertsch, 1991). According to Wertsch, the mediational means used by individuals in a situation "shape the action in essential ways" (p.12) such that the actor, the action, and the mediational means cannot be isolated in any meaningful way. In other words, the teachers' specific use of language shaped students' participation in the cognitive tasks of inquiry. For example, language can be used to index complex scientific ideas: a "stable" population does not stand for a fixed pattern in the data but rather a category of patterns in which the population level fluctuates within a certain range. Clarifying or coming to consensus around a scientific term therefore accomplishes more than simply defining a term: the term itself becomes a tool for students to use in their analysis. In this way, teachers use language to give students analytical tools with which to participate in reasoning tasks such as data analysis. Furthermore, by calling attention to particular analytical terms, teachers also constrained the boundaries of the very tools students had to work with during their analysis: students did not use random terms during their analysis, but instead were limited to terms such as "stable", "unstable", and "fluctuating". These linguistic terms therefore mediated students' cognitive action by defining the tools with which they conducted their analyses.

Similarly, language can be used to mediate students' work with complex representations in inquiry. Representations in science such as graphs, pictures, and diagrams encode phenomena into a form that condenses (and hides) both complex scientific information and the processes used to create those representations. Teachers can help students use language to both decode and unpack the information and processes in representations into a form more accessible to them (words). However, with language as the mediational means, students understand these representations in particular ways. For example, teachers did not describe the graphs as “three wavy lines that seemed to change randomly”, but instead categorized and brought order to the representation using scientific language. In this way, language again defines the ways in which students understand and decode the information in representations.

Finally, language can be used to privilege important steps in a practice. By using discourse markers at certain points during discussions, teachers use language to communicate transitions, next steps, and distinctions between parts of practices. Language therefore becomes a scaffolding tool for students’ participation in inquiry practices, cluing them in to which reasoning steps they should be engaging in when.

The instances in which Denise and Sherry used aspects of the social dimension to facilitate work in the cognitive dimension makes sense given literature in the nature of science about the social nature of scientific practices. The process of scientific knowledge construction is a social one (Driver, Newton, & Osborne, 2000; Longino, 1990; Grene, 1985), depending on argumentation and debate to establish “valid” scientific knowledge. The intersection between the social and cognitive dimensions are examples of ways in which teachers may attend to the social and cognitive dimensions simultaneously in classrooms. It is important to note that we would not expect students to engage in the full complexity of scientific practices as scientists would, since they clearly do not have the range of experiences or the knowledge base to do so. Instead, I are encouraged that this analysis was able to describe teachers attending to some of the complexity of inquiry practices and use the dimensions synergistically to facilitate students' cognitive reasoning about scientific ideas.

For example, as they attempted to share the responsibility for learning with their students, Denise and Sherry gave students opportunities to take on more active roles as producers of knowledge within the scaffolded environment of the classroom. In this way, they were participating in some of the "traditions" and "techniques" of the scientific community as they engaged with complex scientific content. By building consensus around scientific ideas, the teachers gave students opportunities to engage in the social process of hearing the results of other students' investigations into the same problem and deciding which were points of convergence across all investigations. Therefore, even though I did not see students involved in much argumentation and debate around these ideas, students nevertheless got the opportunity to engage in the process of publicly sharing results that then became absorbed into the larger community of the classroom.

The intersection between the social and cognitive dimensions also indicates some ways that teachers may change social patterns in classrooms to accomplish important cognitive work in inquiry. As I argued earlier, inquiry investigations often involve students in large, open-ended investigations that necessitate collaboration in order to answer the overall driving question and accomplish the goals of the investigation. This collaboration may involve a departure from traditional classroom roles. In this analysis of Denise and Sherry, I saw ways in which teachers can define students' roles in the classroom to share responsibility for reasoning and to take advantage of the diversity of students' ideas to illustrate the complexity of scientific principles. In this way, teachers used social interactions—consensus-building, co-construction of chains of reasoning, and sharing responsibility—not just to make sure that students participated in discussions but to make sense of the scientific ideas. For example, by trying to build consensus, teachers not only poll the students for their ideas but in doing so they also try to articulate points of agreement or disagreement between students. This is important for having productive discussions and for converging on the important ideas in a lesson.

Finally, one intersection I did not explicitly explore is the intersection between the social and linguistic dimensions. However, this analysis implies that these dimensions are also inextricably linked. For example, as I illustrated earlier, teachers used the discourse marker "why" to signal to students that they needed to provide evidence or reasoning for claims they made. By using this marker, teachers simultaneously deflect the responsibility for providing that evidence on to the students, thereby forcing students to articulate their own knowledge. In this way, teachers scaffold the cognitive task of providing a scientific explanation that includes a claim, evidence, and reasoning both through language use and through social interactions. The cognitive, social, and linguistic dimensions as being very interconnected in inquiry practices. As we have seen from this analysis, language plays an important part in furthering the cognitive work of inquiry tasks—as analytical tools or discourse markers—and these inquiry tasks are themselves collaborative. Therefore, the language gives students a medium through which they can have conversations about important scientific ideas. As Longino (1990) writes, "a common language for the description of experience means that we can accept or reject hypotheses, formulate and respond to objections to them" (p.70). Without an agreement on the use of scientific terms or a way in which to decode information from data or representations, students would have no way to converge on explanations of scientific phenomena.

This intersection of dimensions points to one way teachers can operationalize what Aikenhead (1996) calls "border crossing" into the culture of science. By supporting students' reasoning about scientific ideas through the use of the cognitive and social dimensions, students have opportunities to participate—in a scaffolded environment—in authentic aspects of scientific practices. As a field, we need a better understanding of the effects of this type of support on students' understandings of the nature of scientific practices, but I see this analysis as a first step in exploring the dimensions around which this border crossing may be supported in classrooms.

Synergistic nature of dimensions and challenges for students

In this study I found two important ways that teachers can use the dimensions of inquiry synergistically to facilitate students' reasoning about important scientific ideas. The two intersections that I describe: that of the social and cognitive dimensions and the linguistic and cognitive dimensions highlight a few ways teachers try to make the multidimensional nature of inquiry practices explicit during complex investigations. As I mentioned earlier, I take the perspective that inquiry practices represent practices in the Discourse of science and that these practices embody many of the epistemological values of the community of practice of scientists. These norms for practices may or may not be familiar to students and therefore represent a site where support from the teacher may be necessary. The intersection of the linguistic and cognitive dimensions that I describe represents one way teachers can call attention to scientific language, model how to apply that language to various practices such as data analysis, and signal next steps in an investigation. In doing so, they communicate the norms for applying scientific terms like "stable" to an analysis of data, or for backing up claims with reasoning and evidence. However, cognitive work in inquiry is not only reflected in new ways of using language but also in new types of social interactions. By defining social roles in the classroom in particular ways, teachers not only gave students opportunities to engage in inquiry practices but also accomplished important cognitive work as well.

Therefore, the teachers accomplished two important goals in the intersecting of these dimensions of inquiry. The first is to call attention to norms for inquiry practices and the second is to make these practices accessible to students. Lemke (1990, 1998), Halliday (1998), Roth (1998) and others argue for the complex ways in which science encodes information in both language and representations. This can result in a privileging of scientific information because it seems inaccessible, too complex for the everyday student. Teachers used language in certain ways to decode this information and make it more accessible to students. Second, teachers made practices more accessible to students by valuing students' participation in inquiry practices and scaffolding that participation.

However, while this intersection of dimensions furthers our understanding of how teachers support students in complex practices, it also raises questions about the challenges students face in inquiry science. Researchers taking a sociocultural approach to schooling suggest that because school requires students to negotiate between the culture of school and their out-of-school cultures, we need to make the rules for participation in school practices explicit to students (Delpit, 1988). Specifically, learning how to engage in school science—with its domain-specific reasoning practices and complex language use—is like learning a new culture (Aikenhead, 1996), and students need a cultural guide to help them navigate through it. The teacher and curriculum materials, as such a guide, need to negotiate between students' everyday beliefs, understandings, and needs on the one hand and domain-specific practices and content on the other.

I began this study with the perspective that part of how teachers introduce students into the Discourse practices of science is to provide support along the cognitive, social, and linguistic aspects of those practices. As I hypothesized what this support might look like, I imagined that while teachers might use many strategies to engage students in practices along the three dimensions, this support would be obvious to the observer. For example, I imagined teachers having discussions with students about the differences between scientific arguments and everyday arguments between peers, explaining that scientific arguments were critiques of evidence and not personal attacks. While this type of discussion did occur (albeit infrequently), most of what I found instead was a range of explicitness in Denise and Sherry's support of inquiry practices. I found the teachers modeling scientific language use without explicitly explaining that they were really communicating their expectations for how students should use scientific language. I found them defining roles for themselves and their students without explaining what those roles were. While this should come as no surprise given limited classroom time and teachers' need to balance multiple demands while teaching (Lampert, 1995), it raised some questions for us about the challenges facing students as they learn how to engage in inquiry practices.

For example, I found the teachers' cues for social aspects of inquiry tasks to be the most tacit out of the three dimensions. However, as I illustrated from previous examples, Denise and Sherry were still able to accomplish important work in the cognitive dimensions despite the subtlety of their cues to the students. How do students pick up on these tacit cues? What understandings of inquiry practices—specifically, the cognitive, social, and linguistic aspects—do they construct for themselves? These are important questions to answer if we are to design learning environments that make complex practices accessible to all students.

CHAPTER FOUR:
SITUATING TEACHERS IN THE TRADEOFF SPACES BETWEEN ELEMENTS OF INQUIRY IN TENSION

Introduction

Inquiry-based science presents challenges to teachers and students because of its departure from traditional science instruction that emphasizes science as a static body of facts to be memorized (Schwab, 1966; Roth, McGinn, & Bowen, 1996). For students, inquiry learning involves a complex system of practices with different aspects coming to the fore depending on instructional context. While engaging in inquiry, students practice skills such as forming a research question, predicting, analyzing data, and creating models (Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; White and Frederiksen, 1998). All the while, students must grapple with unfamiliar norms for scientific language use and learn how to appropriate that language as cognitive tools for their inquiry activities (Lemke, 1990; Chapter 3, this dissertation). For example, as they learn how to engage in the practice of data analysis, students must also learn how to use appropriate levels of specificity for describing trends in data. Finally, at the end of an inquiry investigation, students present the results of their research to their peers and receive feedback on such dimensions of their work as the merits of the evidence to back up their claims. Students therefore experience science both as an individual and collaborative process as they construct meaning through interactions with their teacher and peers. Inquiry therefore may also involve unfamiliar social roles for both students and teachers, where teachers share responsibility for learning with students who take on proactive roles in the classroom and sometimes find themselves acting as the authority for a given topic (Brown & Campione, 1996).

Students cannot, however, be expected to know how to engage in such practices and roles simply by being given the opportunity to do so (Palinscar, Anderson, & David, 1993; Yackel & Cobb, 1996). For example, creating a social environment in which students feel encouraged to share their ideas is perhaps necessary but not sufficient for supporting complex inquiry practices and student-to-student interactions (O'Connor & Michaels, 1996). Teachers play a key role in supporting students in their inquiry endeavors. However, providing such support is a complex task in and of itself. Teachers must make sense for themselves what "inquiry" means at the same time that they adapt curricula to meet the needs of diverse learners and are accountable for student learning (Windschitl, 2002). Because inquiry represents such a departure from traditional science teaching, teachers must also negotiate between the individualistic culture of school in which students are individually responsible for the "right" answer and the collaborative culture of inquiry science (Hogan & Corey, 2001). Finally, teachers need to have a thorough understanding of both the scientific content and the nature of the inquiry practices they support, since they construct certain images of the nature of scientific practices through their enactments of inquiry curricula (Hammer, 1997; Kelly, Brown, & Crawford, 2000; Crawford, Kelly, & Brown, 2000)

Therefore, supporting students in inquiry science is a complex task that involves multiple dimensions of practice: inquiry presents many goals that must be balanced and they may be in tension with each other. For example, helping students engage in a complex practice like data analysis may be in tension with covering all of the important content in an inquiry unit. In attempting to balance these demands during instruction, teachers' enactments may be described in terms of tradeoff spaces in which they make choices about how to best meet the needs of their learners while simultaneously meeting the demands of the curriculum. These tradeoff spaces occur when two instructional alternatives are in tension, both of which are important to attend and which are ideally in balance.

Understanding where teachers fall in the tradeoff space between instructional alternatives is useful to curriculum designers as they attempt to design learning environments that support students (and teachers) in engaging in ambitious types of practices. By understanding the instructional strategies teachers use to enact challenging inquiry lessons, designers can better design curriculum materials that support teachers as they create ambitious learning environments for their students. Having a description of the strategies teachers might use to attend to multiple demands of inquiry can be useful for teacher educators to give teachers options for balancing the challenges that might emerge during inquiry instruction. In this study, I identify and explore some of the tensions that emerge as teachers enact an inquiry-based curriculum and use their teaching strategies to describe their place in the tradeoff space between elements of inquiry that may be in tension. I will use teachers' interview data to explore to what extent teachers are aware of the multiple challenges they face during inquiry. Finally, I will use students' interview data to explore how teachers' positions in particular tradeoff spaces may affect students' understanding of the nature of scientific inquiry practices.

Inquiry as a Discourse: Building on previous work

In previous studies (Chapters 2 and 3, this dissertation), I attempted to capture some of the complexity of teachers' support of inquiry practices by building on the perspective of inquiry as a Discourse (Gee, 1996) and introducing a new framework for characterizing this support.. I argued that inquiry practices embody not only norms for scientific reasoning but also norms for social interaction and language use that are valued by the scientific community. Because these norms, such as backing up claims with evidence and reasoning in scientific explanations, often differ from norms for everyday practices (Reif and Larkin, 1991), they represent a site where teacher support is necessary for students to engage in inquiry practices.

Using this perspective, I explored two teachers' enactments of an inquiry-based curriculum and found that their attempts to support students in inquiry practices could be characterized by three dimensions of inquiry: cognitive, social, and linguistic (Chapter 2, this dissertation). I defined the cognitive dimension as involving reasoning about scientific ideas and the reasoning tasks of inquiry such as data analysis. The social dimension included any aspect of the task that involved teachers' and students' roles in whole-class and small-group work. For example, teachers may communicate to students (either tacitly or explicitly) that their role during a whole-class discussion is to question each other. The social dimension also included any attempts the teacher made to engage students in the social nature of inquiry tasks (Longino, 1990)—for example, engaging students in argumentation or debate around certain scientific ideas. Finally, the linguistic dimension included any aspect of the task that involved specific ways of using language as a tool for engaging in a cognitive task (Wertsch, 1991). The linguistic dimension involves scientific ways of using language. This could mean defining a scientific term or process, modeling ways to use language when analyzing data or communicating scientific ideas, and translating representations into words. For example, a teacher may explicitly define a scientific term such as "stable", or they may re-word a student's answer to make it more analytically precise.

I also found that these dimensions intersected in interesting ways that lent insight into the mutually supportive nature of these dimensions (Chapter 3, this dissertation). For example, teachers used discourse markers such as "why" to signal the need for evidence to back up claims. These discourse markers, part of the linguistic dimension of inquiry, were important in facilitating work in the cognitive dimension because they signaled next steps in reasoning and helped students understand what to do next. Teachers also seemed to take advantage of the multidimensional nature of the practices themselves to support work in two dimensions simultaneously. For example, the practice of data analysis involves using categories to "group" data, or find patterns in the data. These categories are linguistic terms that become analytical tools with which to conduct the analysis. Before engaging in the analysis, therefore, teachers and students needed to come to a shared understanding of these linguistic terms in order to be able to discuss these analyses with one another. I found that the practice of data analysis itself afforded an interesting overlap between the cognitive and linguistic dimensions that the teachers seemed to take advantage of.

Teaching as operating within tradeoff spaces

In this study I push on this multidimensional perspective of inquiry practices to identify aspects of inquiry that may be in tension within and across dimensions of inquiry. Recent research into teachers' enactments of inquiry-based curricula in both mathematics and science suggests that teaching is more accurately described as managing dilemmas and working within tradeoff spaces rather than making clear-cut decisions (Lampert, 1995; Ball, 1993; Hammer, 1997; Windschitl, 2002, Sandoval & Daniszewski, 2004). For example, Windschitl (2002) describes four planes along which inquiry teachers face dilemmas: conceptual, pedagogical, cultural, and political. Within each of these planes, teachers face challenges in implementing inquiry teaching in their classrooms. In just one of these, the pedagogical plane, teachers face challenges of how much freedom they should give students to construct their own ideas, what roles she and the students should play, and how to manage students talking to each other rather than to the teacher.

Teachers of inquiry curricula need to address challenges in all four planes, sometimes simultaneously. The intersection of these planes creates tradeoff spaces within which teachers must balance the demands of each plane and make choices about where to invest valuable classroom time. I will describe in more detail in the discussion how this work builds on Windschitl's model of four planes of dilemmas. I use it here as an example of aspects of inquiry teaching that could be in tension with each other and point to the challenge for teachers to balance these needs during instruction.

What we as a field still need, however, is more detailed descriptions of what it looks like in classrooms when teachers are in tradeoff spaces between different aspects of inquiry. How do teachers attend to multiple demands of inquiry? Are the teachers aware of the tradeoff spaces within which they seem to be working? What strategies do they use? The work in this study extends earlier work on tradeoffs and managing dilemmas by presenting an analytical framework for not only identifying the tradeoffs that arise as teachers enact inquiry curricula but also for describing how teachers deal with these tradeoffs. I use my analytical framework that I developed in earlier work and explore how it helps identify teaching tensions and where teachers are in the tradeoff space between them. I explore the possibility that teaching dilemmas arise when teachers attend to aspects of inquiry practices not only within the cognitive, social, and linguistic dimensions but across dimensions as well. For example, when a teacher attends to social aspects of inquiry such as making sure all students' ideas are heard, does this come at the expense of aspects in the cognitive dimension such as coming to consensus around key scientific ideas? This is important for both curriculum designers and teacher educators in order to better support teachers—through curriculum materials and professional development opportunities—in understanding the types of difficult pedagogical decisions that might arise as they enact inquiry curricula.

One way to explore both the tradeoffs that emerge during instruction and the strategies teachers use to manage them is to observe different teachers enacting the same curriculum. Because teachers need to balance so many demands simultaneously, and teachers all work within different instructional contexts, it is unlikely that two teachers would use exactly the same strategies and represent the same location in the tradeoff space between elements in inquiry in tension. The variation between teachers then gives us some understanding of different strategies for managing the same dilemmas. For example, one teacher may struggle to elicit participation from her students while another teacher may have students who engage in lively discussions and debates without much prompting. Each of these teachers would have to balance managing students' participation with having students explore scientific ideas, but they may do so in very different ways. In our previous studies of teachers enacting inquiry-based curricula (Tzou, Reiser, Spillane, & Kemp, 2002; Kemp, Tzou, Reiser, & Spillane, 2002), we found that teachers exhibited a range of practices between lessons as well as key variations in practice between teachers in the same lesson. We argued that this range of practices could be partially explained by the teachers attempting to manage teaching tensions that arose during their enactments. In this study, I propose that how teachers manage dilemmas that arise between the cognitive, social, and linguistic dimensions of inquiry may help explain variation between teachers in terms of how they enact inquiry curricula. Finally, uncovering these tensions and where teachers are in the tradeoff spaces can uncover goals for professional development if teachers do not realize the cost of pursuing one instructional goal at the expense of another.

Research question

The analysis in this study first identifies aspects of inquiry that may be in tension and then describes where teachers fall in the tradeoff space between them. I then attempt to explain the variation between the teachers in this study through my analysis of the teachers' strategy use during their enactments of challenging inquiry lessons. The first question I ask in this study is: given that teachers need to balance the demands of multiple dimensions simultaneously as they enact inquiry curricula, what tensions arise for teachers between and within inquiry dimensions? Although I found in a previous study (Chapter 3, this dissertation) that the three dimensions of inquiry can mutually support each other, in this study I will explore how the demands in each dimension can actually be in tension. For example, the demands in the social dimension to renegotiate classroom roles may be in tension with demands in the cognitive dimension such as covering the scientific content. The second question I ask in this paper is: how do teachers' pedagogical strategies determine their position in the tradeoff space between elements of inquiry that are in tension? In exploring this question, I describe the strategies teachers used as they enacted an inquiry-based curriculum. Finally, my analysis for this second research question lead to the development of an analytical framework that identified the specific demands of inquiry that teachers attempted to balance as they negotiated teaching dilemmas. By being able to describe how the teachers in this study dealt with tensions between dimensions, I argue that we can better understand the range of strategies teachers might use to manage dilemmas in inquiry teaching. Therefore, the final question I ask is: what was the nature of the variation between the teachers in terms of where they are in the tradeoff space between multiple aspects of inquiry which may be in tension?

I will use as the basis for my analysis two teachers' enactments of the same eighth-grade inquiry-based science curriculum. In order to answer the first two research questions, I used both observational and interview data to analyze how the teachers supported students in all three dimensions of inquiry. I explore the teachers' strategy use in order to understand how they seemed to address challenges that arose in each dimension. I will show data from teachers' interviews to explore the extent to which teachers were aware of the teaching tensions I observed in their classrooms. To answer the third research question, I will compare the teachers across the same lessons in the curriculum in order to understand how the teachers varied in their strategy use and, consequently, where they are in the tradeoff space between elements of inquiry that are in tension. For example, in the tension between aspects of the cognitive and social dimensions, one teacher may emphasize social issues such as egalitarian participation and sharing of authority while another teacher may take a more directive approach to make sure she deals with cognitive issues such as reasoning about important scientific ideas at the expense of emphasizing collaboration between students. By carefully describing the tradeoff space within which teachers are working in terms of specific dimensions of inquiry, I hope to systematically account for variation between teachers as they enact inquiry curricula. As I will describe in my analysis, the strategies teachers used all have advantages and disadvantages, but the point is to describe different approaches teachers have in the face of competing demands of teaching inquiry. Finally, in light of where the teachers are in the tradeoff space, I will use students' interview data to describe students' perceptions of challenges in the cognitive and social dimensions such as how the teacher helps them reason about scientific ideas and how students see their own roles in sensemaking discussions.

Tensions between elements of inquiry: multiple challenges of inquiry

As I described in previous sections, I explore in this study how my analysis of teachers' strategy use can lend insight into where they fall in the tradeoff space between elements in the cognitive, social, and linguistic dimensions of inquiry. Because teaching science as inquiry involves attending to multiple demands simultaneously and because classroom time is a limited resource, teachers need to make choices about which aspects of inquiry to bring to the fore. These choices may depend, among other things, on teachers' perceptions of the needs of their students, their own understandings of inquiry, or their comfort level with the scientific content. For example, one dilemma that may arise for teachers in inquiry is between elements in the cognitive and social dimensions. Teachers may feel a need to support students in the elements of the cognitive dimension, making sure they cover the scientific content and supporting students' reasoning strategies. However, this may be in tension with elements in the social dimension such as giving students the freedom to take on more responsibility for their learning, asking and answering their own questions and exploring their own avenues of investigation. While these two elements of covering the content and giving students freedom to explore their own ideas may not necessarily be in tension, teachers need to balance the demands that each goal presents, carefully managing students' ideas so that they may be tied in to the relevant scientific ideas (Hammer, 1997). If they allow students too much freedom to explore their own questions, this divergence may not lead to converging on important scientific ideas. On the other hand, if teachers are too directed in their guidance, students may not have the opportunity to construct their own ideas and reason for themselves about relevant scientific ideas.

In this section I present two pairs of elements in tension and describe, through my analysis of the teachers' strategy use, where each of them falls in the tradeoff spaces between the elements. The first is between elements in the cognitive and social dimension and the second is between elements in the cognitive and linguistic dimensions. The goal of the analysis is not to describe an exhaustive list of tensions that arose during Denise and Sherry's teaching. Rather, my goal in this analysis was to use my analytical framework to identify the teaching tensions that may arise during inquiry and explore how those tensions may be suggestive of central challenges for teaching in inquiry.

I had two goals going into this analysis. For example, one of the tensions I will describe—between the elements of *reasoning about scientific ideas* and *eliciting students' participation*—is a central concern of inquiry. Teachers need to find ways to involve as many students as possible during knowledge-building discussions in inquiry, but they also need to make sure that students are engaging in reasoning about important scientific ideas. My analytical framework was able to describe, through Denise and Sherry's strategy use during key inquiry lessons, where both teachers were in the tradeoff space between these two elements of inquiry. My intent, therefore, is not to pass judgment on whether the teachers were "better" or "worse" at teaching inquiry. Given that inquiry is not a monolithic set of practices (Songer & Lee, 2003), the point instead is to show the range of practices that teachers may use as they attend to multiple demands of inquiry along cognitive, social, and linguistic dimensions.

Cognitive and social dimensions in tension: Reasoning about scientific ideas vs. eliciting students' participation

One of the challenges to teaching science as inquiry is helping students engage in collaborative scientific practices. Scientific knowledge is socially constructed through argumentation and exchange of ideas (Hogan & Corey, 2001), and this view of science as collaboration and discussion is one of the guiding principles behind inquiry in the *National*

Science Education Standards (NRC, 1996; NRC, 2000). It may be difficult, though, for a teacher to elicit students' participation during class discussions if classroom norms and students' prior experiences are not conducive to students taking on such active roles. Furthermore, simply having students participate in discussions is not sufficient for using those discussions to help students reason about scientific ideas. The teacher's role, too, needs to be an active one—mediating students' ideas to relate them to relevant scientific concepts. Therefore, the teacher needs to strike a balance between having students share the results of their own investigations and bringing consensus and closure around key scientific ideas. The teacher needs to use students' participation not as an end in and of itself, but as an opportunity to build consensus, argumentation, and discussion around key scientific principles.

However, these two goals—of eliciting students' participation and reasoning about scientific ideas—may be in tension with each other as teachers attempt to cover all of the scientific principles in the curriculum. One risk a teacher faces as she opens up the discussion to students' ideas is that students' responses may not be relevant to the task at hand. Or, students' responses may lead the class down an unproductive path from which the teacher may have difficulty diverting students. Both of these possibilities take valuable class time away from covering the content ideas in the curriculum. Furthermore, the teacher herself may face challenges in simply managing all students' ideas, determining which ideas are similar and different to each other, and which ideas may lead to productive reasoning about scientific concepts. This tension is across the cognitive and social dimensions of inquiry: the element of *reasoning about scientific ideas* is a cognitive element because it involves students in relating the results of their investigations to key scientific ideas. The element of *eliciting students' participation* is a social element because it involves a definition of classroom roles, in which the teacher must share control of the discussion with students and the students must take on more active roles.

One can imagine, in the tradeoff space between these two elements, that one teacher may focus on eliciting many students' participation while failing to come to consensus around important scientific ideas. Alternatively, at another point in the tradeoff space, a teacher could simply state scientific ideas for students and only give a few students the chance to publicly reason about those ideas before moving on. In the tradeoff space between these two elements, there may be an "ideal" balance between students' participation in discussion and reasoning about scientific ideas in a productive way. I will describe how, through their strategy use, Denise and Sherry fall on different points in this tradeoff space. As I will show, Denise's strategy use reflects her struggle to elicit students' ideas at the same time that she remains in control of the flow of ideas. On the other hand, Sherry's strategy use reflects her struggle to manage many students' ideas and tie them back to the important scientific content in the unit.

In the following examples, students have just completed analyzing data that showed the effects of the sea lamprey on three species of fish in the Great Lakes: the trout, whitefish, and chub. Students analyzed the line graphs shown in Figures 1a-d. To scaffold their analyses, teachers had students divide the graphs into four time periods: 1910-1944, 1944-1963, 1963-1969, and 1969-2003. These lines appear in Figures 1a-d and help organize the discussions in the transcript examples below. Prior to analyzing these graphs, students were asked to predict, based on their knowledge of food web interactions between the sea lamprey, trout, whitefish, and chub, what the sea lamprey's effect would be in each species of fish. The food web interactions are shown in Figure 2. After they completed their analyses, they were asked to explain the patterns they saw in the data based on these food web interactions.

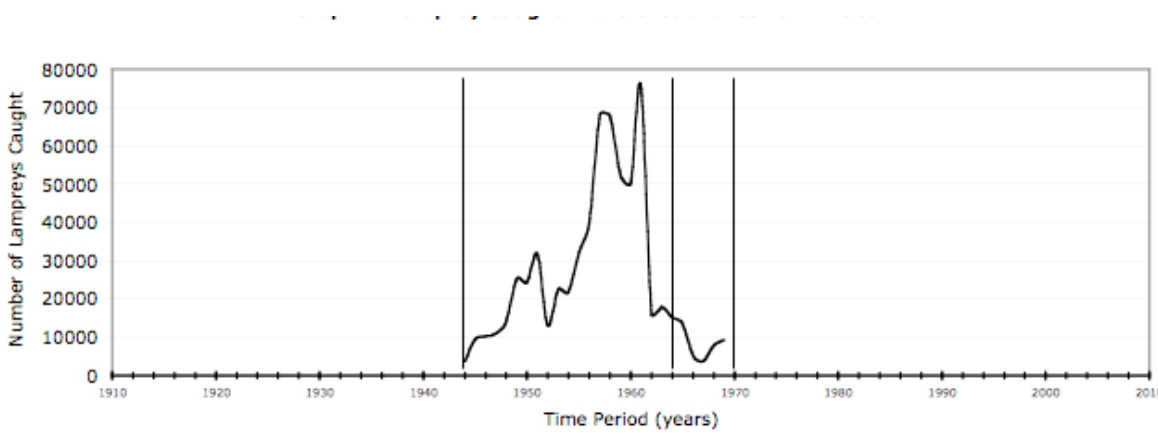


Figure 8: Number of sea lamprey caught in Great Lakes between 1944 and 1969.

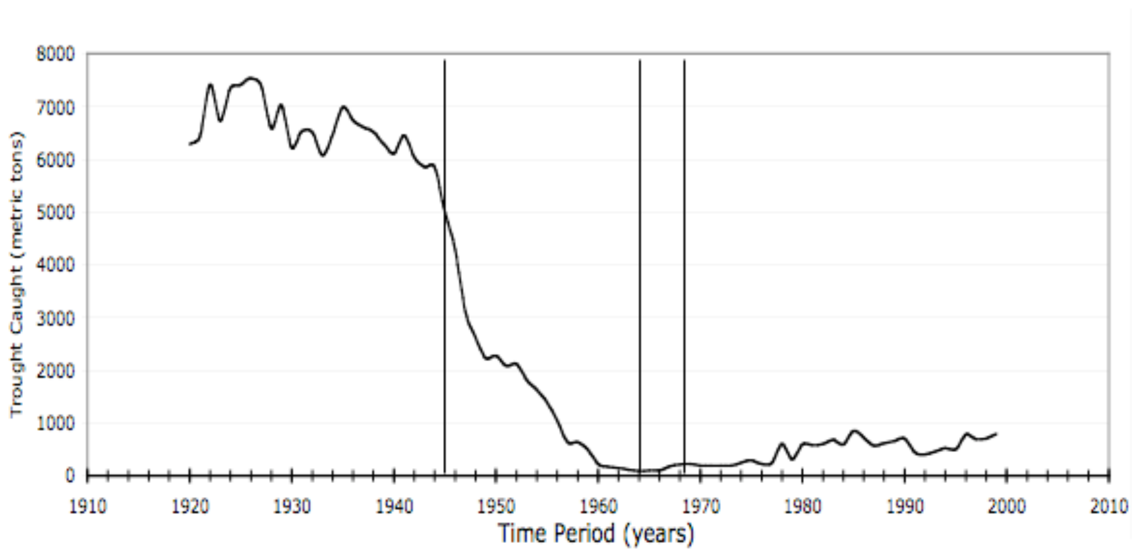


Figure 9: Graph showing the trout caught in the Great Lakes between 1920-1999

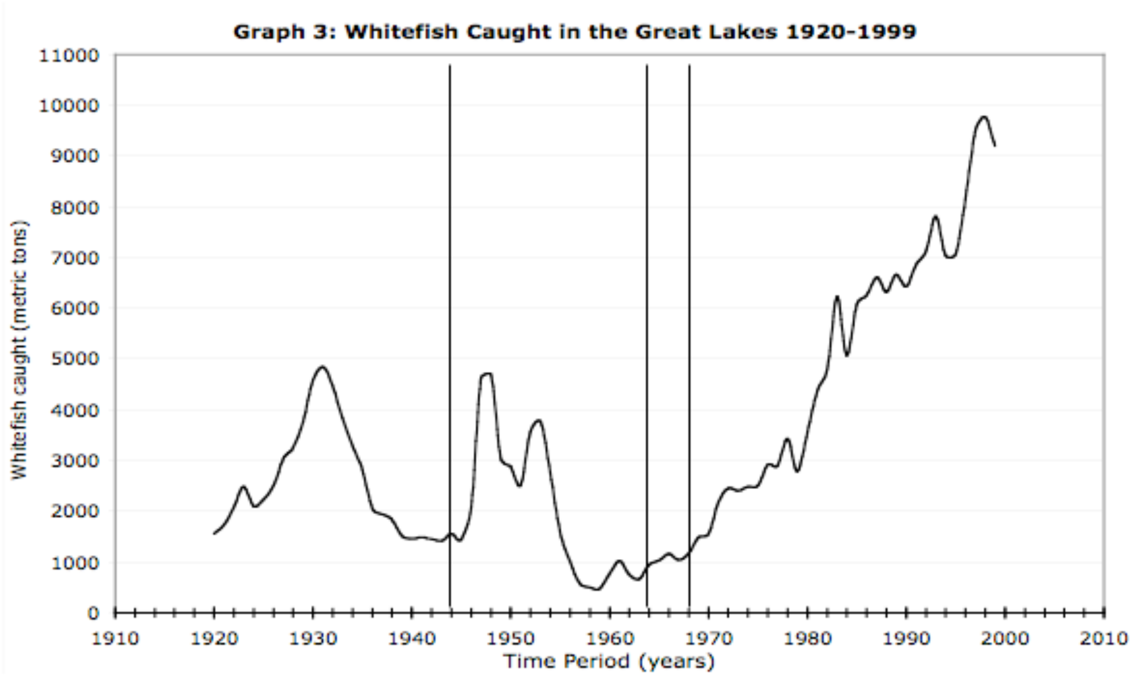


Figure 10: Graph showing the whitefish caught in the Great Lakes between 1920-1999

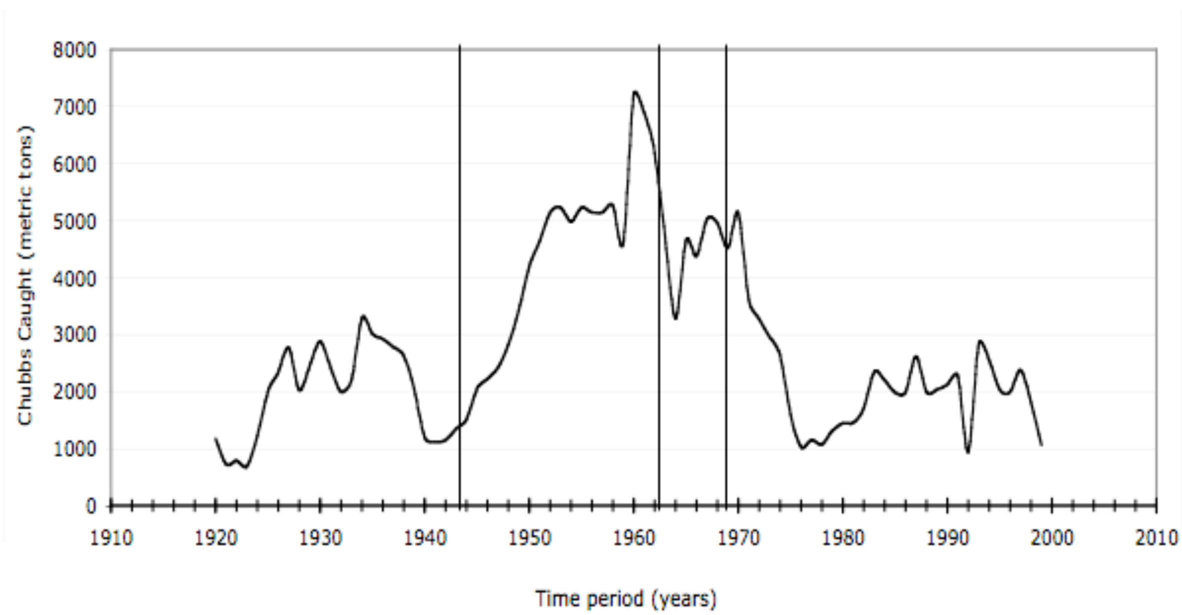


Figure 11: Graph showing the chub caught in the Great Lakes between 1920-1999

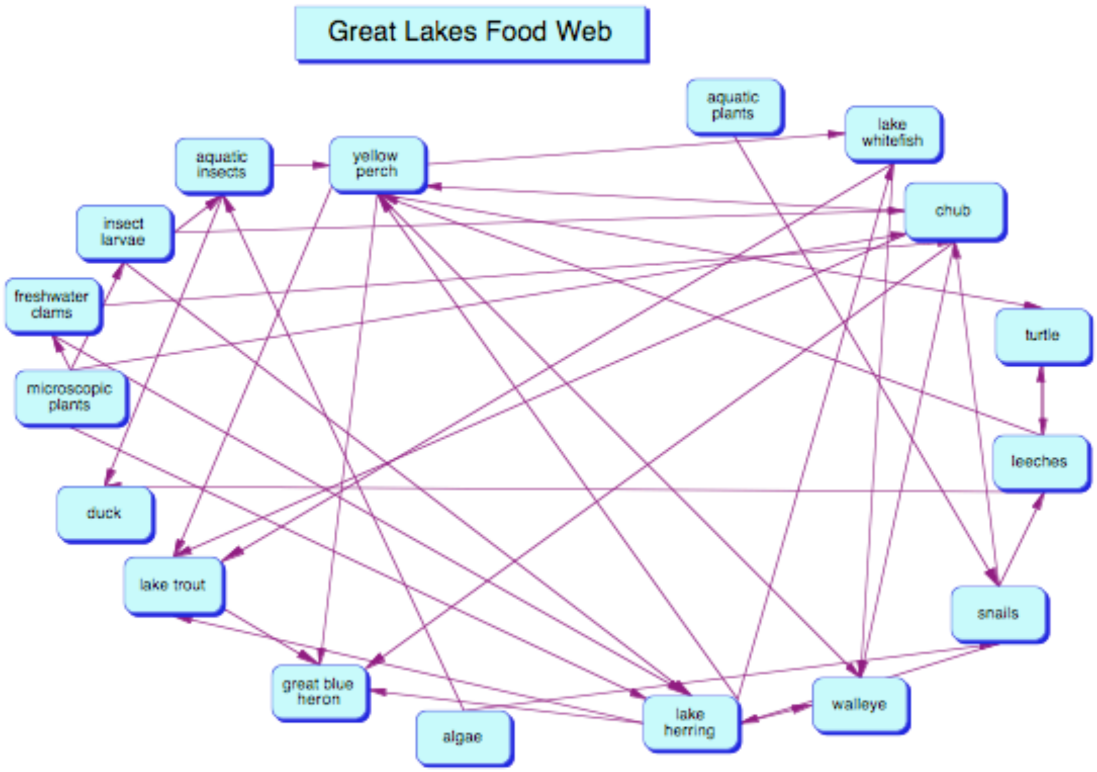


Figure 12: Food web interactions in the Great Lakes food web

As I described earlier, these elements are in tension because teachers need to encourage students' participation in discussion while at the same time covering the content ideas at hand. The following example is representative of how Denise managed whole-class discussions and reflects Denise's attempt to elicit students' participation and have them reason about important scientific ideas. She does this by attempting to co-construct an explanation with the students for the pattern they see in the population of whitefish between 1910 and 1944.

315 Denise: What are we going to say about the whitefish between 1910 and 1944?
316 Students: Decrease, unstable
317 Denise: Unstable. Why are they unstable?
318 Frank: Because it increased and then it went down.
319 Denise: It rose and then it…
320 Frank: decreased

321 Denise: Now what do you guys remember—when you made the prediction, I want you guys to remember it rose and then it dropped. You made that prediction, remember that. What did it say?
322 Larry: Chubs increased and then decreased.
323 Denise: Chubs increased—I mean whitefish increase and then decrease. Probably something to that. I want you to remember that. Why do you think it would increase and then decrease? Lampreys came in.
324 Larry: Oh yeah. Turned on them
325 Denise: Turned on them. But why were they increasing for a while?
326 Larry and Eddie: No predators
327 Denise: Right. Who was gone?
328 Eddie: The lake trout
329 Denise: Trout. And then the lampreys turned on them and look what happened.

In this example, Denise attempts to have the students both share the results of their analyses and construct explanations for the patterns that they found in the data. She uses a combination of moves to support this discussion. The first, which is repeatedly used in this example (lines 319, 321, 325, 327), is *asking a chain of closed questions*. I define this strategy to mean that as she asks a question, Denise clearly has an answer in mind. For example, in line 319, she essentially asks a fill-in-the-blank question when she says, “It rose and then it…”. By using this strategy, Denise is able to elicit students’ participation at the same time that she controls the flow of ideas in the discussion. This strategy also allows students to participate in a fairly safe way, since Denise often provides the stem of the answer in the question she asks. For example, in line 321, she says, “You made that prediction, remember that. What did it say?” The answer to the question simply entails students looking back on their worksheets for the predictions they made at the beginning of the lesson.

The second strategy she repeatedly uses in combination with the first is *repeating students’ words*, which we see in lines 317, 323, 325, and 329. This strategy serves as a cue for students that they have the correct answer. By using this strategy, Denise structures most of the interactions in this example as IRE interactions (Cazden, 1988; Lemke, 1990), in which the teacher initiates a question, the student responds, and the teacher evaluates. If one were to only look at the *structure* of her interactions, one might therefore conclude that Denise was a very traditional teacher, only interested in eliciting "correct" answers from her students and using discussions to review answers rather than explore ideas. Indeed, this pattern of interactions is often used by traditional teachers to drill students on answers they should already know, not to explore new ideas.

However, looking more closely at the *substance* of the discussions, Denise uses these discussions to co-construct ideas with students. In the following exchange, Denise builds on students' ideas to construct an explanation for the pattern of "increasing and decreasing" that they articulated at the beginning of the example.

321 Denise: Now what do you guys remember—when you made the prediction, I want you guys to remember it rose and then it dropped. You made that prediction, remember that. What did it say?
322 Larry: Chubs increased and then decreased.
323 Denise: Chubs increased—I mean whitefish increase and then decrease. Probably something to that. I want you to remember that. Why do you think it would increase and then decrease? Lampreys came in.
324 Larry: Oh yeah. Turned on them
325 Denise: Turned on them. But why were they increasing for a while?
326 Larry and Eddie: No predators
327 Denise: Right. Who was gone?
328 Eddie: The lake trout
329 Denise: Trout. And then the lampreys turned on them and look what happened.

By reminding students of their predictions in line 321, she gives them credit for predicting this same pattern even before they analyzed the data. She says, "you made that prediction, remember that". She then uses students' ideas to build an explanation for this pattern. Notice that although she asks known-answer questions and conducts IRE interactions with the students, Denise is building to an explanation for the pattern in the whitefish data that when the sea lampreys were introduced, ate the trout (the whitefish's predator), and this resulted in the increase in whitefish. Then, when the lake trout population was depleted enough, the lampreys "turned on" the whitefish—that is, the lamprey began to prey on them, causing the observed decrease in their population. This is a scientifically accurate explanation for the pattern the students observed in the data, and one that is also scientifically sophisticated. This explanation involves reasoning through a chain of events, beginning with one change in the ecosystem and tracing that change through multiple species in the food web. Furthermore, Denise did not simply tell students the answer, nor were students simply recalling an explanation that they already knew. Instead, Denise and the students were jointly constructing this explanation, based partly on Denise's prompts and students' analyses of the data. Notice that in the above interaction, the students contribute important pieces of the explanation. Larry contributes the reasoning behind the observation that the whitefish population increased and then decreased: that the lampreys "turned on them". Eddie then contributes the fact that the whitefish increased temporarily because the lake trout, its main predator, was being depleted by the sea lamprey. Therefore, although Denise provides the structure for students in which they do not need to take risks in their answers, she builds on their ideas and engages them in important aspects of the inquiry practice of data analysis.

Denise's teaching moves support, to different degrees, both the goals of the social element of *eliciting students' ideas* and the cognitive element of *reasoning about scientific ideas*. The goals are in tension here because if one focuses on eliciting students' ideas at the cost of reasoning about scientific ideas, students may not understand how the patterns in the data related to the scientific ideas of food webs. Through her chain of questioning, Denise provides a strong structure within which students can share their ideas, a structure that runs of the risk of shutting down students' participation. At the very least, this structure of closed questions limits the freedom of students to share any idea that they may have. However, although she controls the flow of ideas in the discussion, Denise manages to eventually bring students to construct important scientific ideas with her. Therefore, through her strategy use, Denise manages to elicit students' responses without re-negotiating social roles in the classroom. However, by remaining the authority during the discussions, she is able to cover the relevant scientific ideas. Thus, while attending to both goals, her strategy use reveals more of a focus on ensuring scientific ideas perhaps at some cost to eliciting students' ideas and having more exploratory discussions with them.

In order to more fully understand how Denise negotiates this tension, however, it is useful to reflect on several aspects of her instructional context as well. First, she reports that she constantly struggled to elicit students' participation during discussion. While she saw the value in having whole-class discussions, she also realized that they were a risky endeavor for these students. This class was a high-performing class according to the school's standardized test scores, but they were accustomed to reading out of a textbook and answering questions on worksheets individually. Denise realized that this unit was a radical departure from the instructional formats in which these students had been successful. In the following excerpt from an interview with Denise, she talks about the class's transition from doing book work to doing an inquiry-based unit:

> Denise: I'm not a person who cares if it's [the answer is] right or wrong so I don't know. I think it's just their culture, I mean that particular group it's, it's the way they've been brought, I don't know. They're supposed to be the top. You know they're not competitive really but they're competitive within themselves.
> CT: Within themselves. They have high expectations of themselves.

> Denise: Of themselves. It's a little scary. Plus they're—and I think that's part of the issue is those kids are so used to being so good at a textbook that this is too different for them and they are having a hard time with the transition.
> CT: Do you see this transition being harder in this class than the transition was in the other classes?
> Denise: Yes.
> CT: Ok.
> Denise: The other kids were more willing to take that leap because you know they didn't have much to lose [laughs]. They didn't. And these guys do. They're good at this thing. They give me the questions and the answers. They're good at it. And it's hard for them to take that extra leap and say wait a minute. This is different. I have to actually think? You know, come up with some kind of strategies? It's tough.
> …
> CT: what about the discussions? How do you think those are going?
> Denise: Eh, I'd like more participation because it's the same kids…Although in this unit I've seen different kids kind of come alive. Some of the kids have backed off and other kids that I was totally not expected have come alive. So I'm not quite sure. I guess it might just be a matter of you know, telling those other guys to be quiet and have other kids report out. And then this is a tough age. Because a lot of kids don't want to be called, you know, don't single me out. You know, it's hard on them. I don't know. I'm struggling with that part of it.

Several interesting aspects arise out of this interview. The first is that Denise says she does not care if answers are right or wrong. She is more interested in students articulating their ideas and "thinking" independently, coming with "some kind of strategies". However, in her strategy use, she has many interactions with students that reflect traditional IRE interactions. Upon surface observation of Denise, one might conclude that, indeed, the purpose of whole-class discussions is as informal assessments, making sure students got the "right" answer. From the interview data, however, Denise seems more interested in eliciting students' participation than having them share the right answer. She says, "I'd like more participation because it's the same kids", acknowledging that in discussions, the same students seem to participation the majority of the time.

Denise also acknowledges that what students are being asked to do in this unit is a new experience for them both cognitively and socially. Denise says, "And it's hard for them to take that extra leap and say wait a minute. This is different. I have to actually think? You know, come up with some kind of strategies?" According to Denise, the *Survive* unit is different cognitively because it asks students to come up with their own ideas, "some kind of strategies", and this is very different from finding the answers in a textbook. She also says, "And then this is a tough age. Because a lot of kids don't want to be called you know, don't single me out. You know, it's hard on them…I'm struggling with that part of it." This points to the complexity of the challenges Denise faces in teaching this unit to her students: they are not accustomed to doing the types of thinking being asked of them, and the social norms have not been established in her class so that students feel comfortable sharing their ideas in class. Therefore, the interview data point to Denise's awareness of the cognitive and social elements in tension—trying to elicit participation while at the same time getting students to reason productively about scientific ideas.

Denise's example points to one explanation for where she is in the tradeoff space between *eliciting students' ideas* and *reasoning about scientific ideas*: students have been asked to do at least two tasks that are radically different from what they may be used to in school science. The first is to reason in a deep way about scientific ideas. This is very different from answering questions in a book because it involves extracting information from complex data and putting several pieces of the puzzle together into a coherent explanation. To make the task perhaps more intimidating, however, students are also being asked to conduct this reasoning in a public forum. This is "scary" and students may not be willing to "take that leap" into active, public participation if they are used to getting the "right" answer, or at least getting the "wrong" answer privately—on a worksheet that only the teacher can see. This may at least partially explain why Denise minimizes the cost of students' contributing to discussions by asking very structured questions. In this way, she can elicit students' contributions in a fairly safe way. Another reason for her questioning strategy may be that it is the only way she has been able to elicit *any* participation from her students. So although she values open discussions and participation from many students, this strategy of asking closed questions represents a compromise between an ideal sensemaking discussion and the reality of her instructional context.

Denise also co-constructs the chain of reasoning with students, thereby engaging the students in a collaborative knowledge-building process at the same time that any one of the students may not feel responsible for providing too much of the reasoning themselves. In Denise's case, therefore, we can see her students' initial participation in inquiry practices such as collaborative sensemaking at the same time that we see her supporting them in complex scientific reasoning. The scaffolds Denise put in place during discussions therefore served to introduce students to public sharing of ideas in a safe way while they simultaneously allowed her to cover the scientific content in the curriculum.

In Sherry's enactment of this lesson, there is a very different combination of moves that emerge to place her differently in the tradeoff space between the elements of *eliciting students' ideas* and *reasoning about scientific ideas*. In the following example which was representative of her whole-class discussions, students have already made their predictions and analyzed the data in Figures 1a-d. Sherry has pulled the class together for students to share their analyses. To scaffold students' analyses, part of the task as stated in the curriculum materials was to identify trends in the data as stable, unstable, decreasing, or increasing. In the following example, Sherry's class spent much of the time negotiating the meaning of "stable" and "unstable".

16 Sherry: Does anyone disagree with what Aiden just said?
17 Mary: Um, I believe my group put this too, for the stable—we put unstable.
18 Sherry: So you think it's unstable why?
19 Mary: Because it doesn't stay in one place.
20 Student: It doesn't have a pattern.
21 Jen: It doesn't have a pattern, it's not, it's not like between, it's not in that range and just like it has no high, no peaks, it's not like up down, up down you know.
22 Kevin: It looks stable to me. [T turns out the light]
23 Jen: I don't think that's stable.
24 Sherry: How many people think that's stable? [some ss raise hands]
25 Sherry: How many people think it's unstable? [some ss raise hands]
26 Sherry: Ok. Here's my feelings on this and I may be wrong and I may hear about this later today. Um, if you can justify why you think it's unstable or why you think it's stable, I think it's ok. Clearly I mean there's going to be some that are very obviously stable and there's going to be some that are very obviously unstable. Just hold one moment please. This next one, is it stable or unstable?
27 Students: Unstable
28 Sherry: Unstable. Um, I think that if you can sufficiently support your reasoning, or show me your reasoning behind why you think –there's no pattern, it falls out of the range—I think that I would, if it was a test question, I would give you credit for it. So don't panic if you've got something different than what other people have as long as you can defend what you say. And that works in my room, it doesn't always work in everybody else's room. Some teachers like a definitive, everyone's got to say the same thing, so just to let you know when you go to high school. You've got something to say?
29 Kevin: It decreases the same amount every time.
30 Sherry: We're here? We're here. [Points to the overhead]
31 Kevin: It barely is the same. See how every time it valleys it's about the same pattern.
32 Sherry: Ok it's about the same. If we took a…
33 Kevin: The same distance away.
34 Sherry: [holds up a ruler to the overhead] So it goes about a centimeter here, centimeter there—is that what you're saying?
35 Kevin: Yeah
36 Sherry: Ok. So in this time period, what happens? Annie?
37 Annie: It's an overall decrease
38 Sherry: Overall decrease? Stable or unstable?
39 Annie: Unstable.
40 Sherry: Ok. Why do you think that happened?
41 Annie: Because the sea lamprey started eating them.
42 Sherry: Ok. Anybody disagree with that? Does this coincide with the time when we look at…
43 Students: Yes
44 Student: That's when the sea lamprey [inaudible]
45 Sherry: [puts up overhead of lamprey data] Whoa. Look.
46 Jess: What is that, lamprey?

47 T: Mm Hm.
48 Jen: So it's going up. It's eating more up there of that—what is that, trout?
49 Sherry: Yeah. This is trout. Now this is not perfectly—now I don't know if it's like this or…[T has trout and lamprey graphs on top of each other on the overhead]
50 Student: 1970, that's when it starts like—it took time for it to decrease.
51 Sherry: Why did it take time for it to decrease? Do you guys remember with the um, the simulation that we did with Net LOGO?
52 Kevin: It wouldn't suddenly just die, it could live longer and…
53 Sherry: Say it
54 Kevin: If there's a less population, it wouldn't die off immediately, it takes a little bit of time.
55 Sherry: Right it takes time for patterns to show up or for things to happen in environments. Do you remember when we did the net LOGO, when the snakes went up, did the population of rabbits go down immediately? No, it took some time. They were always just a little bit off. It wasn't like they were right there together in the same place. Snake population goes up, rabbit population starts going down just a touch after that population goes up ok? Next time period, 63-67? Um, Erin, we haven't heard from you.

In this example, Sherry uses two strategies to run this discussion. The first is to *elicit multiple interpretations* of the same phenomenon. Examples of this strategy use are in lines 16, 24-25, and 42. In line 16, Aiden has just shared his interpretation of the data as "stable" and Sherry asks "Does anyone disagree with what Aiden just said?" In a typical IRE exchange, the teacher asking such a question following a student's response would mean that the student's response was incorrect or somehow unacceptable (Yackel & Cobb, 1996). In this case, however, it seems to be a shared social norm that students are expected to share their interpretations even after other students have shared theirs. An example of this is in the exchange between Mary, Jen, and Kevin in lines 17-23. In this exchange, the teacher has elicited other interpretations after Aiden's. After Mary shares hers, Jen and Kevin jump in and either support or refute her interpretation without direct prompting from the teacher. This strategy, therefore, seems to serve as a prompt for students' participation, a norm that was established in the class earlier in the school year.

However, this strategy does serve a number of purposes. First, it communicates to the students that there are multiple possible answers to the same questions based one's interpretation of the data. Second, it allows Sherry to remain neutral in terms of evaluating students' responses at the same time that she emphasizes important aspects of scientific practice. For example, after students share their interpretations, Sherry probes them for reasoning (lines 18, 40, 51): asking, for example, "Why do you think that happened?". Although she is non-evaluative in terms of whether the students' responses are "right" or "wrong", she still emphasizes the importance of reasoning to back up claims. This is a very important part of making scientific claims in science. Again, in a typical IRE interaction, the teacher usually responds to a student's answer with a comment that evaluates that answer as being correct or incorrect. In Sherry's case, she uses non-evaluative responses such as asking for clarification (lines 30 and 34) or asking for other interpretations (lines 24-25 and 42).

This strategy of eliciting multiple interpretations of the same phenomenon is a costly one in terms of time. If a teacher has *all* students sharing their responses, this can take time and is potentially unproductive unless the teacher mediates the discussion and ties students' ideas back to the relevant scientific ideas at hand. In fact, this particular discussion took 63 minutes altogether, whereas the analogous discussion in Denise's class took 38 minutes. This was a consistent pattern of difference between the two teachers, with Sherry's discussions lasting twice and sometimes three times as long as Denise's. Although time is no indication of the productiveness of a discussion, Sherry's strategy use of eliciting multiple interpretations tended to be very costly in terms of time, leading her to enact only half of the curriculum in the same amount of time that it took Denise to enact the entire curriculum.

Sherry uses another strategy, *making connections for students*, which serves to tie students' ideas to the important practices and concepts in the unit. This strategy was used to prompt students' reasoning, pointing students to relevant ideas and practices from earlier lessons. The important characteristic of this strategy is that the *teacher* does the work of connecting students' ideas to important ideas and practices in the unit. In the previous exchange, Sherry uses this strategy in a couple of cases. In lines 26 and 28, Sherry explains that students should not worry about getting different answers, because the important point is to back up answers with evidence or reasoning. This connects back to the practice of backing up claims with reasoning, a central practice throughout the unit. In line 55, Sherry again uses this strategy of making connections to make connections for students between their current lesson and a previous lesson in which students used a computer simulation, NetLogo (Wilensky, 1999), to investigate how food web interactions can translate into fluctuating population levels. Sherry uses this as the basis for explaining the patterns in the data. In both of these examples, Sherry takes a step back from the lesson to emphasize a generally point that is relevant to the unit. In lines 26-28, she connects students' discussion of "stable" and "unstable" to her expectation that there are different possible answers to the same question. She uses this as an opportunity to emphasize her expectation that students use evidence to back up their claims. In line 55, Sherry generalizes the patterns students saw in the data to other examples from a previous lesson. This strategy serves as a way to connect students' discussion to important practices and concepts in the unit.

Sherry is at a different place in the tradeoff space between *eliciting students' ideas* and *reasoning about scientific ideas* than Denise. Recall that in Denise's example, she remained very much in control of the discussion but used students' ideas to co-construct sophisticated explanations for phenomena. Because of the structures she had in place to scaffold the discussions, Denise's prompts asked for very specific responses from the students, thereby allowing her to control the flow of ideas during the discussion. In Sherry's example, she attempts to share control of the discussion with students most of the time. There are student-to-student exchanges, and Sherry's prompts are more open-ended and her responses non-evaluative. However, although she manages to tie the discussion back to previous important ideas in the unit, she does not use the students' sharing time as an opportunity to co-construct these ideas with the students. These strategies are not mutually exclusive: Sherry could have fielded students' responses at the same time that she categorized them around important ideas in the unit, thereby building consensus around these ideas while she was open to all students' responses. Instead, she fields students' responses and then takes the floor and ties the ideas together herself.

Interview data from Sherry can partially explain the strategies I observed her using during whole-class discussions. The following excerpt comes from her post-interview. Sherry is responding to my question of how she sees whole-class discussions contributing to the class's learning. Because of the design of the unit, whole-class discussions were the main events around which ideas from students' investigations were synthesized and students came to consensus around the important scientific concepts in the unit. Therefore, it was important for me to get a sense for how the teachers themselves saw the role of these discussions in learning:

> I think it's good because the quieter ones, sometimes they get a little bit braver. I think it depends on how you run a discussion. And it's really—sometimes it's really hard for me to be good with—"that's a possibility but…" without going "are you nuts? Did you read the question? I got a different book here!". I think I'm getting better at that as the years go by. "That's a possibility, well what about this?" Because I'm trying to get the other kids to talk more. Um, I think it's good because there are some kids that are clearly more educated and they need to open up and tell people. Crystal doesn't talk. She's so frickin smart. She doesn't talk. I'm like, girlfriend, you gotta tell us what you know. I would say that that's probably it. They get out of control. I'm never good at keeping them—I'm very easily distractable. Well let's go over there. Part of it is when I went to college to be a science teacher, it's so exciting to learn some of this stuff… But I remember being like,

> are you kidding me? Is that how this works? And I love to give that to the kids. And so some people say, "So ok, I have 5 females and 40 males." And part of my brain goes, "Oh my God, why do you think that is?" I love animal behavior and looking at adaptation, and then I go foom! Oh, I'm sorry we were supposed to be doing a lesson today?

From this excerpt, Sherry recognizes challenges in running whole-class discussions in this unit, and these can be characterized in terms of the social and cognitive dimensions. When she says,

> sometimes it's really hard for me to be good with—"that's a possibility but…" without going "are you nuts? Did you read the question? I got a different book here!". I think I'm getting better at that as the years go by. "That's a possibility, well what about this?" Because I'm trying to get the other kids to talk more.

we can see her efforts to remain neutral during discussions to encourage participation from more students. This is consistent with her use of non-evaluative strategies such as asking for clarification and eliciting multiple responses for the same question. These strategies may serve to encourage participation by making whole-class discussions less like assessments in which students must provide the correct answer and more like opportunities to explore ideas. The second challenge Sherry recognizes is trying to focus students' discussions around the task at hand. She draws on her own sense of wonder when she first studied science and wants to transfer that feeling to her students:

> Part of it is when I went to college to be a science teacher, it's so exciting to learn some of this stuff… But I remember being like, are you kidding me? Is that how this works? And I love to give that to the kids.

Perhaps because of this, she capitalizes on students' questions and wants to explore ideas with them even if these ideas stray from the original task. However, she is "easily distractible", letting the students' and her own excitement take her away from the important scientific ideas. This may partially explain why she often uses monologues to tie ideas together: she realizes the ideas she needs to cover but most of the class time has been taken up exploring ideas with students.

This analysis lends some interesting insight into where each teacher was situated in the tradeoff space between the social and cognitive elements in tension. In Denise's case, I found that although her interactions with her students during whole-class discussions seemed very traditional, she was actually accomplishing important work through those interactions. Although she elicited students' ideas through very directed questions, she then built on students' responses to those questions to arrive at sophisticated scientific ideas. However, this strategy use has its consequences. Although she managed to elicit students' participation, we do not get a sense for how well the other, non-participating students in the class understood the reasoning that she constructed with Frank, Larry, and Eddie. Because she did not ask for multiple responses to the same question as Sherry did, there is no evidence of widespread engagement in the collaborative sensemaking. Denise therefore seemed to strike an interesting balance between the two elements in tension: while she did manage to elicit students' responses to her questions, she may have limited the exploratory nature of the discussion with her own questioning technique. On the other hand, her strategy use may have been a reflection of her perception of her students' readiness to engage with complex scientific ideas and the social format of participating in whole-class discussions. Because the knowledge-building discussions in this unit represented new experiences both on a social and cognitive level, Denise provided very structured support for students' participation in them. Therefore, in the tension between these two elements of inquiry, she falls more focuses more on getting students to *reason about scientific ideas* than *eliciting students' participation*.

In Sherry's case, she uses open, non-evaluative strategies to have students share their ideas but then uses monologues to connect students' comments to the scientific ideas in the unit. The time spent for students to share their ideas was exploratory but not used in the service of coming to consensus around the important concepts of the unit. Sherry's strategy use was therefore very dichotomous—sharing responsibility with students during the bulk of the discussion and then taking over the responsibility to connect students' ideas to important concepts in the unit. This strategy use also has its consequences. Although Sherry's non-evaluative strategies allowed most of the students to share their ideas, we do not get a sense for how the students saw their own ideas in relation to others. Furthermore, because Sherry herself tied the ideas together at the end of the discussion, we do not get a sense for how well the students in the class were able to relate the ideas in the lessons together for themselves. Because the majority of Sherry's discussion time was eliciting students' responses, this left little time for focusing on content. In the tension between these two elements, Sherry's strategy use therefore places her at a different point in the tradeoff space than Denise, focusing more on *eliciting students' participation*.

As I said earlier, my goal in this analysis was not to judge Denise and Sherry on being "good" or "bad" inquiry teachers. Instead, I wanted to use my analytical framework to explore the challenges the teachers faced and how attempting to meet one instructional goal can have costs in another goal. This analysis points to the challenge of attending to and achieving multiple goals of inquiry simultaneously that may be in tension. My analysis of Denise and Sherry's strategy use describes the tradeoff space between the elements of *reasoning about scientific ideas* and *eliciting students' participation*. If a teacher frequently intervenes in order to make sure students are reasoning about scientific ideas, the result may be that students are too busy answering the teacher's questions to really engage with each other. On the other hand, if a teacher attempts to have all students participate, it may be difficult to manage students' ideas productively around the important scientific concepts.

However, the ideal balance may not necessarily be a "50/50" split between the two elements. Where the students are in terms of their experiences with inquiry will also influence how much a teacher is able to emphasize one element over another. For example, in Denise's case, her students were unaccustomed to sharing their ideas with each other. The tasks in the unit represented new experiences for them both cognitively and socially. Therefore, simply eliciting *any* participation from the students may have been a great achievement in her class. On the other hand, Sherry's students were completely comfortable talking to each other because they were grouped together as a class for two years as the "high" track in mathematics. Therefore, Sherry's main challenge may have been trying to take advantage of the class's enthusiasm to share ideas but reign in that discussion so the students were able to reason about the scientific concepts. Therefore, the teachers' strategy use may have been a reflection of the students' experiences with inquiry and the classroom norms put in place well before the teachers enacted our unit.

Linguistic and Cognitive dimensions in tension: Understanding scientific terms vs. reasoning about scientific ideas

Understanding scientific language is a complex task which involves, among other things, understanding how graphs and charts can be decoded into language, how to use everyday terms like "explanation" in specialized ways, and how language can translate into norms for action (Lemke, 1990; Lemke, 1998; Halliday, 1998). Students who have limited experience with this specialized genre of language use may have difficulty engaging in inquiry activities in which they need to understand how to translate scientific language into actions such as extracting information from graphs, making claims based on evidence, and using linguistic terms as analytical tools. Furthermore, teachers are not always explicit in helping students understand scientific language. They may build definitions of terms over several interactions with students, leaving it up to the students to infer the meaning of these terms for themselves (Lemke, 1990). Second-language learners may have difficulty extracting the specialized meanings of scientific terms and may, instead, build their own meanings of terms based on their everyday experiences (Rosebery, Warren, and Conant, 1992). Scientific language use therefore represents a potential obstacle to students' participation in inquiry practices and a site at which teacher support is crucial.

In inquiry curricula, scientific terms are introduced with which students may have little or no formal experience. However, understanding scientific terms is often imperative for students to engage in inquiry practices such as data analysis. For example, students may be asked to label a certain pattern in the data as "stable" or "unstable" with little guidance as to how to operationalize these terms in the context of their investigations. Although these terms seem simple, they actually require a fair amount of scientific understanding about fluctuations in population levels of species, how long those fluctuations last, and how regular the fluctuations are. There are a variety of ways teachers may support students in understanding scientific terms. They may, for example, attempt to define and explain any potentially confusing terms at the beginning of a lesson, hoping students will then apply these definitions in the course of their investigations. They may define and explain terms in a just-in-time basis, as they come up during students' investigations. Or, they may allow definitions to emerge from students' experiences and discussions, having students construct their own definitions of terms from the context of their investigations. Whatever method teachers use, they need to balance helping students *understand scientific terms* with helping students *reason about scientific ideas*. Students need to see the utility and power of scientific terms as well as how to apply them to their own investigations. As Lemke (1998) writes,

> The "concepts" of science are not solely verbal concepts, though they have verbal components. They are semiotic *hybrids*, simultaneously and essentially verbal, mathematical, visual-graphical, and actional-operational. (p. 87)

Therefore, the verbal component of a scientific concept, or the label we give to that concept, is just one part of that concept—understanding a concept entails how to apply that verbal label to representations and how to translate that label into actions. This is a complex task for any teacher, one that entails balancing defining terms with providing support for how those terms apply to complex scientific ideas. One can imagine students getting so involved in attempting to use or define a particular scientific term in their investigation that little class time remains for discussing scientific ideas.

In this section I explore how Denise and Sherry's strategy use as they attended to the cognitive and linguistic elements of *reasoning about scientific ideas* and *understanding scientific terms*. As I will describe later, the teachers had very different approaches and therefore are situated at different points in the tradeoff space between these two elements. In Denise's case, she introduced terms in a just-in-time fashion, explicitly defining scientific terms or modeling scientific language use as she introduced them during discussions. She incorporated these definitions of scientific terms into the scaffolded discussions I described in the last section. In Sherry's case, she attempted to allow definitions for complex scientific terms emerge through discussions. However, this strategy left students with sometimes ambiguous definitions for complex scientific terms—terms students could have used in their investigations. Instead, students spent the majority of class time arguing over how to define particular terms, leaving little time for Sherry to cover the scientific content ideas that were the point of the investigation.

Denise attempts to use linguistic terms to support the cognitive work she wants students to engage in. In the following interaction, Denise is reviewing a computer simulation, NetLogo, in which students investigated the effects of an invasive species on a food chain that consisted of grass, rabbits, and snakes. One of the outputs of NetLogo is a graphical representation of all four populations over time, as shown in Figure 7. In line 28 below, Denise shows this graph on the overhead to facilitate the discussion.

28 Denise: Alright. Let's talk about when uh, in the next situation when you added the invasive species. [Puts up overhead from Net Logo showing invasive species graph]
29 Student: Is that kind of stabilized too?
30 Denise: Does this kind of stabilize? What do you think guys? Does this kind of stabilize from probably the point where the rabbits and stuff die to this? Is that pretty stable?
31 Students: Yeah
32 Denise: Yeah. Because it's still going up and down but it's still within a certain range of things. Do you know what I mean by a range of things? Um, doesn't go beyond something or below something. It never dies out. And it still goes up and down. And up and down are called fluctuations if you didn't remember that. Ok. Let's look at this one. What happens to the grass initially in this one? What happens to the grass? Give me an answer—uh, Sam, what happens to the grass in this situation, what happens initially? Look at it. Tell me what happens?
33 Sam: It decreases
34 Denise: It decreases. Ok. Why does it decrease when you add the invasive species? Who eats it?
35 Student: The invasive and the rabbit.
36 Denise: The invasive species eats it and the rabbit eats it. Who's eating it more?
37 Student: The invasive.
38 Denise: Ok. The invasive species eats it. Now, what happens to the rabbits?
39 Cameron: They're going to die.
40 Denise: Well right at the beginning, do they die right away though? The rabbit is the purple one. They went up a little bit and then what happened?
41 Eddie: They decrease because of the competition…
42 Denise: Ok so they started to die off after a while. What happens to the snakes?
43 Student: They die too
44 Denise: they die off too, why did they die off?
45 Larry: No rabbits to eat.
46 Denise: No rabbits to eat. And then what happens to that invasive species?

47 Student: It goes up
48 Denise: It kind of lives happily ever after because what?
49 Larry: No predators, no more competition
50 Denise: No predators, no competition, and what else? It has grass, it has a food source. Ok. Nice job.

In this interaction, Denise again uses the strategy of *asking a chain of closed questions* to both elicit participation from her students and build an explanation around the population fluctuations they see in the data. However, Denise gives students support in understanding these terms by using the strategy of *defining terms* in the context of the discussion. In line 30, she asks, “does this kind of stabilize?” and then in line 32 explains why the population would be called “stable”—because the fluctuations (the “up and down”) are within a certain range. Notice also that the interactions in lines 29 through 32 were prompted by a student asking if a certain part of the graph “stabilized”. Rather than answering the student with a simple yes or no, Denise uses this opportunity to define key terms for the students—terms that will become important analytical tools for students in the next lesson, where they need to apply these terms to analyze data from the Great Lakes food web.

Perhaps between of the way Denise defines terms, she is able to then spend time in the last part of the interaction on helping students reason with the data. In lines 33-50, she walks student through how to analyze the data by asking a chain of questions. These questions have the effect of breaking down the analysis into small steps and allow the students to participate in the analysis without taking on too much responsibility for any one part of the analysis. She first asks what will happen to the grass with the introduction of the invasive species, but she walks them through what to notice and how to do the analysis. Sam responds with a trend from the data, but Denise pushes for a reason behind the trend. This leads Denise and the students to construct a chain of events that ultimately result in the reason for the grass's decrease over time based on the interaction between the species in the food chain.

The following interaction is another example of how Denise incorporates definitions into discussions:

> 109 Denise: Ok. So if I said lake trout, what are you guys going to tell me might happen? Here's the sea lamprey [points to the food web on overhead], here's the lake trout. What's your prediction—up, down, or stay the same?
> 110 Larry: Down
> 111 Denise: And what's the evidence, what are you basing it on, what knowledge do you have when you're making that prediction. Larry, what did you want to say?

In this example, Denise is asking students to make predictions about what will happen to the lake trout when the sea lamprey enters the food web system. As in the previous example, she engages students in the inquiry practice—in this case, making predictions—at the same time that she gives the students support for engaging in that practice by defining key terms for them. In line 99, she says, "what's your prediction—up, down, or stay the same?". She thus simultaneously asks for an action from the student—to make a prediction, and defines the parameters of that action with "up, down, or stay the same". In line 101, she uses the same strategy when she asks, "what's the evidence, what are you basing it on, what knowledge do you have when you're making that prediction". Again, asks for an action from the student—to provide evidence or backing for his prediction—but at the same time she defines what "evidence" means—what you are basing your prediction on, what "knowledge" you have when you are making that prediction. In this example, we see one way in which a teacher may support students' understanding of a term at the same time that she uses that term to elicit some sort of reasoning from the students. This makes sense given that linguistic terms are essentially cognitive tools that students use to reason with, whether they are analytical tools like "stable" or key elements to an inquiry practice such as "evidence".

In these examples, Denise uses the strategy of *defining terms* as she engages students in reasoning about scientific ideas. She seems to incorporate these definitions into the discussions so that she both models the use of the term as she defines the action or reasoning that students should engage in. By looking at her interview data, one can see how aware she is of helping students understanding scientific language because of the high percentage of second-language learners she had in her class. In the following excerpt from her post-interview, Denise expresses her concerns about her students' understandings of scientific terms and some of the ways she tries to support them:

52 Denise: So I think that's what these units do, that there's a purpose to these activities, there's a goal, there's a beginning and there's an end and we're really trying to find out an answer to something. As opposed to we read about density, we learned about it, now let's do an activity on density. That's it. Now that we've investigated it, oh, that's what we call density. I get it now. And I think they get it more when they've explored it first before they actually have to get the standard definition. I think they need to know those standard definitions especially being the ESL kids that we have.
53 Denise: And I think that's where I needed to focus a little bit more on, to make sure they understood the language. You know, the language of the science. And I don't believe I did that through this unit. I think I lost a lot through that.
54 CT: So what do you mean the language of the science?
55 Denise: Well maybe 95% of these kids are bilingual and science is a whole other language that they have to learn. And I needed to step back lots of times and focus on, you know, ok, well what, like natural selection, even though they explored it, I need to go keep going back to it and re-talking about it and re-visiting it and re-teaching it. Because for kids with second language problems, it takes them 10-15 times before it sinks in. They can't just hear it once or twice and I've learned that working here for a few years.
56 CT: How do you think science as a language is different from maybe other things that they're used to? Like other languages, or…I mean, I just think it's interesting because I think we assume a lot when we say "of course, it's natural selection" without breaking that term down for them or…
57 Denise: They need it broken down. Um, when you say natural selection to them, they're like, "ok, so you naturally select something". Yes, but how does that happen? Well natural means to them well it comes from the ground somewhere. You know, I mean, those are the kinds of issues I need to be aware of teaching this kind of kid is I need to

> know where their baseline is. They've got the standard definition—maybe. Even the stuff length, width and height, it's tough for them. They didn't understand—ok, so length is long. Ok. Ok, You know. You have to keep going at it with them.

There are several interesting points that arise from the interview data that support what I saw in Denise's classroom interactions. First, she expresses her concern for providing constant linguistic support for her students. She realizes that because of the needs of the second-language learners in her class, she needs to constantly define and explain terms for her students. This was reflected in how she defined words for students as she used them during discussions. Second, she adds to the students' experiences with phenomena by labeling those phenomena with linguistic terms. She says, "I needed to step back lots of times and focus on, you know, ok, well what, like natural selection, even though they explored it, I need to go keep going back to it and re-talking about it and re-visiting it and re-teaching it." The interview data demonstrate Denise's awareness of the dual goals of having students experience a phenomenon and having students understanding scientific terms like "natural selection".

The interviews with Denise indicate her awareness that her students may come to the class with intuitive understandings of scientific terms. She realizes that she needs to work with her students to refine their definitions of these terms so that they become tools to reason with. In line 57 she says, "when you say natural selection to them, they're like, 'ok, so you naturally select something'. Yes, but how does that happen? Well natural means to them well it comes from the ground somewhere." From this quote, Denise indicates her efforts to both elicit students' understandings of terms like "natural selection" and also help them understand why it is a useful explanatory term when she says, "but how does that happen?"

The way that Denise incorporated definitions for scientific terms in a just-in-time fashion at the same time that she helped her students reason about scientific ideas demonstrates one way in which a teacher might balance the demands of elements in the cognitive and linguistic elements. Denise defines terms in the context of their use, which is one way to help students understand how to use scientific language. The problem, however, may be that because the definitions for terms did not emerge naturally through discussion, the students may not understand how to incorporate the scientific language into their own investigations. Therefore, although Denise is often very explicit in defining terms for students—presumably because of her awareness of the needs of the second-language learners in her class, it is unclear whether the students can really appropriate those terms for their own purposes.

In the tradeoff space between the elements of *understanding scientific terms* and *reasoning about scientific ideas*, then, Denise seems to strike a reasonable balance (see Figure 5). She attempts to give students examples of how to use scientific terms in context, which leaves time during discussions for her to reason about scientific ideas. By not taking up too much class time with discussion over the meanings of terms, she gives students the opportunity to engage with the important inquiry tasks. Her emphasis on scientific terms, however, does point to the importance of establishing a common language around which to engage in inquiry tasks. As the next example from Sherry's class highlights, lack of a common language can lead to sometimes unproductive conversations between students about definitions of terms and consequently distract from reasoning about scientific ideas.

Sherry falls at a different point in the tradeoff space between the elements of *understanding scientific terms* and *reasoning about scientific ideas*. Sherry frequently uses the strategy of *modeling scientific language use* without explicitly defining key terms for students unless specifically asked. In the following example, students are reviewing questions they answered during the NetLogo simulation. In the process, they are sharing their observations about the population levels of grass, rabbits, and snakes as shown in the graph in Figure 3. In this example, Sherry repeatedly uses the term “fluctuation” to describe different aspects of the students’ observations.

73 Student: The rabbits and the snakes both increase…
74 Students: Yeah, that’s what we got.
75 Sherry: So basically, there’s **fluctuations** in what we’re doing, in what we’re seeing, right?
76 Jen: But what happened when we did our variation, the snakes increased, the rabbits at first they increased but then they decreased, and the grass started out good and then it decreased too. It started out increasing and then it decreased.
77 Sherry: Ok, so basically what we see after 50, 60 generations is that there’s some **fluctuations**. Some of you guys saw the snakes go up, some of you saw the snakes go down. Right? Did anybody see the snakes go down? Snakes are always up? Yes? No? The populations are going up and down. Do you think that’s similar to what we saw in the first model?
78 Students: Yeah
79 Sherry: Do you think it happens because of the same reasons?
80 Kevin: Yeah. Not between 50 and 60, they didn’t go down at all. Through 50 or 60 that’s what I’m saying.
81 Sherry: So clearly we had some **fluctuations**, we had different experiences with this model, right? Some people had snakes go up, some had them go down a little bit. When the snakes were first—the snakes were actually squared away, right? Number 3. What did you observe in the population growth of grass, rabbits, and snakes between 200 and 1000? Gary?
82 Gary: The rabbits were going up and then they were also going down. And the grass, when the rabbits were going up, it was going down. When the rabbits were going down, it was going up. And um…And then when the rabbits were going down, um, up, the grass was going down.
83 Sherry: Ok.
84 Gary: And uh, the snakes were balanced.
85 Sherry: The snakes were balanced out no matter what was happening with the grass and the…
86 Kevin: That’s what we had too.
87 Sherry: Did you guys all see that?
88 Students: Yes, no
89 Sherry: Hold on. What they were saying that they saw was the rabbits and the grass **fluctuated**—
90 Jen: What does that mean?

91 Sherry: Moved up and down. So when rabbits are up, the grass is down, when rabbits are down, the grass is up. What the snakes pretty much stabilized.
92 Student: Yeah, they pretty much stayed the same.
93 Sherry: They pretty much stayed the same. What did you…
94 Student: Ours are all balanced.
95 Sherry: So everything is pretty much evening out. Ok.

Sherry uses the strategy of *modeling scientific language use* as she uses the term “fluctuation”, a strategy that involves the teacher using scientific terms or scientific language in the context of an investigation without explicitly defining those terms. In this case, Sherry uses “fluctuation” repeatedly through the exchange to summarize students’ observations (lines 75, 77, 81). However, she also seems to use the term differently during the exchange. In line 77, “fluctuation” seems to mean one population (in this case the snakes) going up and down. In line 81, Sherry follows the word “fluctuation” with “we had different experiences with the model”. Although she goes on to say, “some people had snakes go up, some had them go down”, students may get the idea that “fluctuations” means “different experiences”. In line 89, Sherry says “the rabbits and the grass fluctuated”, implying that “fluctuation” may mean two populations going up and down in response to each other. Finally, when Jen asks, “What does that mean?”, Sherry is forced to give a definition, one that includes only this last sense of fluctuation. However, immediately following this definition, she says “the snakes pretty much stabilized”, followed by talk in lines 92 through 95 about lines “pretty much staying the same”. From a student’s perspective, then, “fluctuation” could *also* mean lines that are stable and staying the same.

All of these senses of the term “fluctuation” are not entirely inaccurate. Single populations can fluctuate in response to certain environmental conditions. Two populations can fluctuate in response to each other, as in a predator/prey relationship. Population levels can fluctuate within a stable range if environmental factors remain relatively constant. Finally different students' experiences with the simulation can "fluctuate" in that they can vary from each other. In this case, the term "fluctuation" can be used to describe a group of patterns in the data, in which either single or multiple populations are increasing and decreasing. Therefore, by using the same term to summarize students' observations during the simulation, Sherry effectively condenses all of those observations into the single term "fluctuation". Although this is not an inaccurate use of the term, Sherry never makes these different senses of the term explicit for students. Therefore, from the students' perspective, it may be unclear when and how to properly apply it to describe their observations. There is evidence of this confusion through students' failure to take up the term despite Sherry's repeated use of it.

Perhaps because of this confusion about how to describe their observations, much of the talk in this example is focused around surface descriptions of the data. While Sherry attempts to summarize students' observations at different points in the exchange by using the term "fluctuation", students do not see the utility of this term for their analyses. If they had, perhaps they would be able to see the similarities between their observations—that all of the populations fluctuated, some within a stable range, some within an unstable range—and gone on to explain the reasons for these patterns. Instead, the discussion was more one of sharing observations without discussing the reasoning behind those observations. Sherry attempts to steer the talk towards the reasoning part of the task when she says in line 79, "Do you think it happens because of the same reasons?" Kevin gives a brief "yeah" but the rest of his response goes on to describe the data pattern.

It therefore seems important to converge on a shared set of linguistic tools that students and teachers can collectively use during their analyses. Speaking the same "language" may then facilitate students' coming to consensus around relevant aspects of their analyses, thereby allowing more class time to be spent on reasoning about the scientific principles to explain the data patterns.

The next examples help to further describe where Sherry falls in the tradeoff space between the elements of *understanding scientific terms* and *reasoning about scientific ideas*. In the following few excerpts, Sherry is asking students to share their analyses of the data in figures 1a-d. All of the following examples come from the same discussion, with the line numbers indicating where the examples occurred in the discussion.

77 Jen: Ok. Um, there is, in that period 1963 to 1969 it's pretty much just there, so I would see it as stable and could justify it—I mean, I don't know if I could justify it, but because that period there, it's not like it's moving up or down, it's pretty much just down there, it's not moving like…

78 Sherry: Absolutely

79 Jen: and even after, even a couple years after, it's still down there and then like, in the beginning of maybe 1980, right? Maybe 1979, around there, it starts, then it starts to go peaking.

80 Sherry: Ok. So we agree that population is good before the trout come in, right? Not the trout, lamprey, right? This is when the lampreys are here [points to the overhead] first really peak? Ok. And clearly there's an impact on the trout population, correct? How's it doing now?

81 Students: Stable, still unstable.

82 Sherry: Would you say it's stable or not?

83 Students: Yes, no

84 Becca: But is it an overall increase or decrease?

85 Sherry: Well it's an overall increase because we end up with almost 1000 in the year 2000 [indicates on overhead] and we started out with a couple hundred.

In this example the students are analyzing the population levels of the trout population. Jen begins by describing the stability of the trout population between 1963-1969 and then the increase in population around 1979. Notice that up to this point, Jen's descriptions are at the level of describing the lines on the graph without mention of the reasoning behind the patterns she observes. In response, Sherry attempts to provide that reasoning by first using the strategy of *summarizing* in line 80 and then *modeling how to use representations to make claims* by pointing to the graph and saying, “clearly there’s an impact on the trout population, correct?” In this way, she provides an explanation for the trend Jen shared in line 79 of the population “peaking”. Notice, however, that the talk immediately turns back to whether or not the population is stable, increasing, or decreasing. In the next example, Sherry moves the discussion to focus on the trout population between 1963-1969.

20 Sherry: Ok. 1963-69? [T goes to overhead] What happens there? Gary?
21 Gary: It’s a stable increase because it’s consistent. It’s an increase because it ends up higher than where it started.
22 Sherry: Ok. Overall stability, overall increase.
23 Becca: [inaudible]…it just kept on rising.
24 Sherry: It’s a short time period so it’s hard to see. Why would you say that this is unstable?
25 Becca: Because it’s just rising…
26 Gary: But that means you’re just looking at the end part
27 Jen: It’s not…
28 Gary: If you were looking at the middle you wouldn’t think it kept on rising.
29 Becca: Hide the middle. I mean the ends.
30 Sherry: Mm hm. I know what you mean. [T goes to overhead and covers part of the graph]
31 Becca: It’s rising. It’s going up and up and up.
32 Jen: Yeah but it’s not having like dramatic leaps. It’s not going dramatically up and down it’s pretty much…
33 Sherry: Is it growing—like if we looked at this as the center point, is it about the same on both sides?
34 Becca: But if you look at where it started off and where that ends—it’s an increase. It’s unstable.
35 Sherry: Ok so there is an increase, right? It starts out lower…so wait. Why would you think it’s unstable?
36 Becca: Because with the other one, the other one we saw? It was stable because it had a, rise and then a decrease…
37 Sherry: So the fact that we have a low point and a high point and don’t really have anything—like if it came back down here? Would that help you?
38 Becca: Yes
39 Sherry: Ok. Just making sure I’m not missing something here. Ok. And other people are looking at this as ok, if I look at this black dot here, it’s going up about the same amount as it goes down. Again, if you can support what you’ve got, if you can defend it, me personally, I don’t have a problem with it.

This example points to the importance of the class having a shared set of linguistic tools with which to conduct and discuss their analyses. In this example, Gary and Becca disagree about whether to call the trout's population stable or unstable during the time period between 1963-1969. In lines 139 to 142, one reason for this disagreement emerges: a question arises as to which part of the pattern on the graph is the most relevant for characterizing the pattern. Gary seems to think the "middle" of the pattern is most important whereas Becca argues for looking at just the beginning and the end. Then in line 145 Jen argues that, "it's not having like dramatic leaps", thereby introducing another aspect of the analysis: how "dramatic" do the "leaps" need to be in the data for it to be characterized as unstable? Finally, Becca explains in line 149 that she based her analysis on a previous characterization in which a pattern was "stable" because of a "rise and then a decrease". Becca thus indicates that her definition of "stable" does not include general patterns of fluctuations but rather a specific pattern of "rise and then a decrease", which is apparently what she sees in this example as well. Jen, on the other hand, seems to have a more general definition of "stable" which she attempts to apply to the graph by saying "its not going dramatically up and down". She seems to be looking for a "dramatic" change in order for a pattern to qualify as "unstable". Notice, however, the students do not disagree on what they see on the graph—they all agree that the graph starts out lower and increases at the end, with a stable area in the middle. Instead, their arguments have to do with which scientific term to apply to the relevant area in the data. Therefore, by attempting to let students construct their own definitions of "stable" and "unstable", the students end up disagreeing on many key points of the analysis: what the defining characteristics of "stable" and "unstable" are, what are the relevant parts of the data that epitomize those characteristics, what precedents to base their analyses on. This discussion brings up important points about the process of data analysis which Sherry could have leveraged at the same time that she helped students defined "stable" and "unstable". However, these arguments take away class time from the reasoning part of the task, which was to explain the patterns in the data rather than simply describing them.

In the next example, Sherry again attempts to steer the conversation away from pure description and more towards explaining the trends.

222 Jackie: To me it looks like it's going to decrease dramatically in 2000.
223 Sherry: You think it's going to drop dramatically.
224 Students: Yeah
225 Sherry: How many of you guys think it's going to drop dramatically? [some students raise hands]
226 Sherry: Why? What supports that?
227 Student: It's a hypothesis.
228 Sherry: Its an educated guess. So tell me why you think—if—the population will decrease because why?
229 Student: Because the sea lamprey…
230 Sherry: Ooohhh
231 Student: Because the chubbs are also decreasing and I think it's like a similar kind of fish.
232 Sherry: Ok so you think it's going to decrease dramatically because the chubbs are also decreasing.
233 Student: Yeah
234 Sherry: Ok. Kevin you had your hand raised for something.
235 Kevin: When someone—I don't remember who explained it—but they told us that if you turn it sideways and do unstable and stable, it really doesn't matter about the huge—it's going about the same distance—you should turn it sideways. So [T turns the overhead]

In part of the discussion Sherry takes advantage of the Jackie's prediction in line 222 of the population decreasing "dramatically" in the year 2000. She asks in line 226, "why? What supports that?" in an attempt to ground the discussion in the context of the sea lamprey investigation. However, this attempt is short-lived when Kevin returns the talk back to attempting to define "stable" and "unstable". Finally, towards the end of this discussion, Jen is frustrated by the vague definitions of the terms and asks Sherry explicitly for her opinion:

253 Jen: Your personal opinion as a science teacher, Ms. S, what do you think?

254 Sherry: Looking at this? Um, I would say, I would say, um, you know what the problem is? I've listened to your arguments and I can look at this and say this is totally—this is stable. There's a clear increase, decrease, it's going along, it's not like it's out of control. Conversely, I can also say it's unstable because we start out really low and we get up high. Is the trend towards an increase? Absolutely. I mean we started out with 1500 metric tons and we end up with a little bit over 9000 metric tons.

Sherry's response is typical of the non-evaluative stance she has taken all along—she validates both the "stable" and "unstable" descriptions of the data while giving no indications as to which she sees as more accurate. This is a clear indication that what matters most to Sherry is not getting the "right" answer but being able to articulate and argue for a position. However, in a school culture in which students are expected to fill in an answer on their worksheets and get evaluated on the "correctness" of that answer, the prospect of there being more than one answer may seem like a scary one. However, this seems to be one of Sherry's main goals in her teaching—to help students see multiple sides of an issue. She emphasizes this point in one of her interviews:

54 Sherry: I think the cool thing is that it makes them aware of their world. I think it shows them that there's no one right or wrong answer which is also what I try to teach them. You know, you should stop logging, ok, well what about the people who rely on logging? And does that bird really matter? Well yes it does, but humans don't think so… It all works in there.
55 CTT: That seems to be something that you emphasize a lot like this whole gray area.
56 Sherry: There's way too much gray. And I didn't know there was gray until I went to college. I was a very black and white girl…The other part of what I do as a teacher is to get them to realize that just because it's written in the regular newspaper doesn't necessarily mean that it's true. And they need to look at those sides. I think that this unit helps. I think that it allows them to see, like Brazil said, that there is no right or wrong.

Therefore, even though the particular discussion I described above did not have to do with social issues such as logging, it is clear that Sherry is concerned about helping students see that "there's no one right or wrong answer". She clearly wants to foster an attitude of skepticism in her students ("just because it's written in the newspaper doesn't necessarily mean it's true) and from the classroom data we have seen her attempting to foster discussion and debate through her discussions. This may explain the general pattern of Sherry's teaching over several examples; a non-evaluative stance in order to foster discussion and debate, fielding multiple responses to the same phenomenon, and allowing students to construct definitions of scientific terms for themselves rather than imposing a strict definition on them.

Based on this analysis, Sherry falls in a different place in the tradeoff space between the elements of *understanding scientific terms* and *reasoning about scientific ideas* (see Figure 5). As we saw in the examples from her enactment, so much of the discussion focused on how to apply the terms "stable" and "unstable" to the data patterns that this distracted from the reasoning part of the task: to explain those patterns based on the food web interactions between the trout, whitefish, chub, and sea lamprey. The discussions were not unproductive, however, because students did seem to be arguing about important aspects of the practice of data analysis: which parts of the data are relevant to the analysis, how to judge a "dramatic" fluctuation, and how fine-grained an analysis to do. But because Sherry did not leverage those points in the discussion, students did not have the opportunity to understand how their arguments did or did not apply to the important task of reasoning about the data.

My analysis of the teachers' strategy use in this tension points to the importance of linguistic elements in reasoning about scientific ideas. In Sherry's case, the lack of consensus around how to use analytical terms as tools in data analysis obstructed the class's productive work in the task. Students were so busy arguing about whether a certain part of the data was stable or unstable that they lost sight of trying to explain the data based on scientific principles of food web interactions. On the other hand, using scientific words without defining them first can also lead to confusion, as we saw in Sherry's example as well. Denise's strategy of providing just-in-time definitions of words seemed to reflect her concern about her students' difficulty with scientific language use and they may have helped students reason about the scientific ideas. However, because of how directed she was, it is unclear what these definitions meant to the students.

As with my analysis of the previous tension, this analysis suggests some of the central challenges facing teachers in inquiry. Getting students to reason about the important scientific ideas in the unit is clearly not a trivial task. My analytical framework begins to articulate the nature of the challenges teachers face in doing accomplishing this. My analysis also highlights the nature of the tension between *reasoning about scientific ideas* and *understanding scientific terms*. Reasoning about scientific ideas requires a common understanding of the language with which to discuss that reasoning with others. As we saw in Sherry's case, if such an understanding does not exist, discussions can stall or become confusing as students use scientific language differently or disagree about how to best communicate their ideas. Simply having the students discuss the definitions of terms does not necessarily lead to productive work with those terms. The teacher needs to do important work to mediate that discussion and bring students to a consensus around language use so that students can move on to the deeper, more productive parts of the task. On the other hand, my analysis of Denise's enactment also suggests that having the definitions for terms and rules for scientific language use simply come from the teacher may not be enough to have students take up that language for themselves.

Again, the "ideal" balance between these two elements may be different depending on the students' comfort with using scientific language to communicate their ideas. In theory, one can imagine the "ideal" case being where the definitions for terms would naturally emerge through students' reasoning and use of those terms. In this way, the definitions would be situated in students' investigations and hold real meaning and purpose for them. However, if teachers already have issues with language use, as in Denise's case where she was concerned about her students' understanding of scientific terms, that teacher may need to be more directed in her support.

Students' perceptions of science work: Insights from student interviews

Given the variation between Denise's and Sherry's strategy use and, therefore, the ways in which they managed the teaching dilemmas I described above, I next explore *students'* perceptions their own roles in each of the classes, the role of whole-class discussions for resolving confusing issues, and how students perceived the role of collaboration in each of the classes. As I mentioned in the opening sections of the paper, I observed one class each from Denise and Sherry, and followed one focus group of four students in each of those classes. I conducted interviews with these students before, after, and one time during the unit, focusing on what we as designers saw as relevant inquiry practices in the unit such as forming analogies between model systems and constructing evidence-based scientific explanations. Although this is a small sample size, there were some interesting differences between the two groups that were worth noting, especially given the variation that I described between the teachers. By exploring students' interview data in this way, I hope to gain a more complete understanding of how the teachers' strategy use may have an effect on students' perceptions of particular aspects of the classroom environment.

In Denise’s class, the focus students described any difficulties they had with the unit in individual terms. The following examples are from Ella and Mike, two of the focus students in Denise’s class:

Ella

1 CT: So what was the example of something that was tricky for you?
2 Ella: This question right here that says why is these data important to scientists studying sea lamprey? I put that the tables, what helped them, the water temperature or something could be changed so they could stop reproducing so much. So it could help them lose up more eggs or something like that so they weren’t reproduce that much.

Mike

1 CT: was there anything that you were confused about, or that was, you weren’t quite sure that you were doing the right thing?
2 Mike: Only right here in the environment, I messed up which environment was the right one. Environment 1 was the fish and I forgot.
3 CT: What do you mean which one was the right one?
4 Mike: Like we went to different things and tried to pick up the food and I didn’t know which ones were like, which one was the fish and which one was the nectar flower and the seeds and something.

Ella’s and Mike’s examples point to two interesting ways in which they situated confusing issues that arose during the unit. The first was that when asked about what they found confusing in the unit, they both pointed to aspects of the worksheets—specific questions or parts of the worksheet that they had to fill out rather than larger conceptual issues. The other way they situated these confusions was in individual terms (“I”) rather than collaborative terms such as “we”. This makes sense given the information from Denise’s interviews that these students were used to answering questions from a textbook individually. However, this is also interesting given my analysis of Denise’s teaching strategies in previous sections. Although in principle she valued having students discuss ideas with each other during discussions, she remained in control most of the time. Therefore, it makes sense that students would still see their classroom roles as doing work for the teacher—answering questions and filling out worksheets—rather than collaborating with their classmates to collectively arrive at an answer.

In Sherry's class, the focus group students described their confusion in terms of "we", indicating that they saw their group and, perhaps, their class collectively having trouble understanding certain ideas. In the following excerpts from two of the students, Andy and Kevin, they describe the confusion the class had about long and short life reproducers:

1 Kevin: Some of it's good and some of it's confusing.
2 CT: Like what?
3 Kevin: The size and proportion and stuff like that when we were talking about how to class in long life and short life.
4 CT: So why was that confusing?
5 Kevin: Like the size. We didn't know what to compare it to.

71 CT: Ok. And was there anything that was hard about this lesson?
72 Andy: At first we kind of still didn't get the thing about the long life and the short life. Like some animals like some animals or living organisms you would think of as long life but then again some of them have characteristics of small life reproducers.

It is interesting that both students were able to recall exactly what the confusion was that the class discussed, even though these interviews took place more than a month after they did the lessons in class. Given that Sherry allowed students to engage in a lengthy discussion about this topic, and that students also worked out the confusion for themselves (with scaffolding from the teacher), it makes sense that this would be a memorable classroom event. It is also interesting that the confusion about the long and short life reproducers was seen by both students as distributed among the class instead of located individually. Both students referred to a specific controversy that the class discussed rather than a particular question or worksheet in their books.

In terms of how the students viewed the role of whole-class discussions, there was again an interesting difference between the focus group students in each class. For Denise's students, they mainly saw whole-class discussions as informal assessments, or opportunities for them to share "correct" answers:

Gabrielle:

21 CT: I notice that Ms. W [Denise] likes to have you guys talk to each other in class. How is it for you to share your ideas in class?
22 Gabrielle: I don't like doing it. I'm not a very good speaker.
23 CT: So is that you don't like talking or you feel like you don't really know the answers?
24 Gabrielle: I like talking but—a lot—but sometimes I feel uncomfortable with my answers and I guess I'm not comfortable with it.
25 CT: Is there anything that Ms W does to make you feel more comfortable with your answers or do you think it's always kind of hard?
26 Gabrielle: Well she—if we get something wrong, she'll let us know why it's wrong and tell us the real answer. And that helps.

Ella

1 CT: So Ms W has you guys try to talk a lot in class. How do you feel about that, sharing your answers in class?
2 Ella: Actually I don't feel nothing bad but it's kind of like, like you feel kind of weird like sharing them because everyone might think like oh, I'm going to tell them my answer and what if it's wrong or it's not the answer they're looking for.
3 CT: Oh, ok.
4 Ella: So it feels kind of weird.
5 CT: So is it because you're not sure you have the right answer?
6 Ella: Yeah sometimes.

Mike

5 CT: Ok. So Ms. W asks you to work in groups a lot and also she calls on people a lot in discussions. Is that comfortable for you to work in groups and share your ideas in class or is that hard?
6 Mike: That's easy. I guess like when I was little I used to be like shy but now I'm not. But it's better to do it with your group and somebody else because then you have like group knowledge and if you get a wrong answer then you won't feel like embarrassed or something like that.
7 CT: Oh because it's not just your answer.
8 Mike: Yeah

In these excerpts, Gabrielle, Ella, and Mike all expressed the idea that having the right or wrong answer was an important element both in classroom discussions and how they felt about their own participation in those discussions. Recall that in my analysis of Denise's strategy use, she used many IRE interactions even though she was, simultaneously, actively constructing new knowledge with the students. I also speculated that these types of interactions could be use simply to drill students on what they knew rather than construct knowledge with students. It seems, however, that the students in the focus group seemed to have picked up on the "assessment" aspect of the IRE interactions despite Denise's goal of exploring ideas through discussion. The focus group students perceived their role in whole-class discussions as providing answers to the teacher's questions rather than constructing knowledge with their classmates or working through confusing issues. Therefore, although Denise accomplished important work through her whole-class discussions, perhaps the social roles in the class had not been re-negotiated to an extent that students could feel a sense of ownership for the new knowledge that they constructed with the teacher during discussions. Alternatively, perhaps the interactions in the discussions were so similar to what the students were accustomed to that they did not see themselves or Denise as doing anything "new".

In contrast, there was a very different perception of classroom discussions from Sherry's focus group students.

Andy:

73 CT: How did you guys work through—because it seems like the whole class was confused about that right?
74 Andy: Yeah. The long life and the short life
75 CT: How did you guys—did you talk it over? Did Ms. S just explain it to you?
76 Andy: We talked it over. We talked it over. Like after Ms. S explained it. The whole group listened and then we talked about it like what would we think it would be. If it had more

characteristics of a long life, we would call it a long life. It probably put a slash, a little short life, something like that.
77 CT: Ok. So does it help when you guys sort of talk through things in a group?
78 Andy: Sometimes yeah.
79 CT: Why is it helpful and why is it not helpful?
80 Andy: So everybody can put their opinions in about the subject. Then, yeah they just put all of their opinions together.
81 CT: So why is that helpful to have everyone's opinions together?
82 Andy: I think everyone's opinions count and as long as like good opinion, you know, some people's opinions might be right. So that's what I think. And then everybody just puts them together. It helps us answer questions.

Kevin:

6 CT: So when you guys get confused like that in class, how do you guys usually figure stuff like that out?
7 Kevin: We just start talking.
8 CT: Why is that helpful?
9 Kevin: Because we can hear other peoples' thoughts how we should do this and pick the best one.
10 CT: Ok so do you think, so when you hear other peoples' thoughts, do they help you understand things better?
11 Kevin: Yeah
12 CT: How?
13 Kevin: because we were talking about the, in the later lesson about the food chain and stuff like that and the direct and indirect and we talked about that and I feel we got it.
14 CT: So why was that helpful to talk it out?
15 Kevin: We learned it better than how she explained it. We got the explanation better and clearer for us.

Brianna:

69 CT: Ok. So let's talk a little bit about, like in this unit we're having you guys work a lot in groups. Why do you think that's important? Or do you think that's important?
70 Brianna: Because it's important because other people's opinions are valued because sometimes when you're thinking of something right away something obvious doesn't pop into your head because you're thinking in a totally different direction. And then maybe Kevin who is in my group will say wait Brianna you didn't think of this. And then once we put it all together it's a better, four heads are better than one, let's put it that way.
71 CT: Ok and what about all of the, because Ms. S has you all talk as a whole class a lot. Does that help you figure things out?
72 Brianna: Just to make sure everyone's on the same page and she never moves on unless everybody knows what she's talking about.

73 CT: How do you think those whole-class discussions help you learn, do you think?
74 Brianna: Sometimes they point out things that I missed by reading something. Sometimes when you're reading you just go over something that you don't think is important and then you realize when someone's talking about it, oh wait a minute I needed to know that.

In these excerpts, there is a very different perception of the role of whole-class discussions than we saw in Denise's class. As I described in my analysis of Sherry's strategy use, she used non-evaluative strategies to keep discussions open and to share control of the discussions with the students. This sense of shared responsibility for learning seems to be reflected in the focus group students' comments during interviews. In Kevin's interview he says, "We learned it better than how she explained it. We got the explanation better and clearer for us", meaning that through discussions, students were able to better understand each others' explanations than the teacher's. This is significant given the difficulty teachers have of getting students to listen to and value each others' comments during discussions. This seems to be a shared norm among at least the focus group students in Sherry's class: Andy says, "I think everyone's opinions count", and Brianna says, "other people's opinions are valued". These students clearly see discussions as forums for hearing and learning from other students' "opinions" rather than providing "correct" answers to the teacher.

This difference in perception between the two groups is interesting given my analysis of the variation between Denise and Sherry's strategy use. Although I make no claims about directly linking the teachers' practices to the students' perceptions (as reflected in their interviews) of the role of whole-class discussions, the differences between the focus groups makes sense given my analysis of the two teachers. Denise's students seemed to understand their roles in the discussions as providing answers to the teacher, and this task was made somewhat intimidating given the expectation to provide the "correct" answer. This may have been part of the reason why it was so difficult for Denise to elicit students' participation during discussions: they were afraid of providing incorrect answers in front of the whole class. My analysis of Denise's strategy use of asking closed questions is consistent with this perception, in that it was clear that in asking many of her questions, Denise had a particular answer in mind. However, perhaps because the classroom climate—in terms of teachers' and students' roles—was only beginning to change, or the students were still not accustomed to taking on unfamiliar types of classroom roles, students perceived the discussions as filling traditional roles of drilling and assessment.

In Sherry's class, on the other hand, the students had the expectation that regardless of whether they had the "correct" answer, discussions were for hearing everyone's opinions and working through controversies. Given this expectation, it is no wonder that students did not feel intimidated to participate: their opinions could only add to the richness of the discussions. This makes sense given y analysis of Sherry's strategy use of eliciting multiple responses and using non-evaluative comments. Although my analysis also pointed out the compromise between *eliciting students' participation* at the expense of reasoning about scientific ideas, students in Sherry's class clearly saw value in being able to use discussions to understand the content ideas.

The students' perceptions from the interview data may lend some interesting insight into the complexity of balancing multiple, often competing demands of inquiry. For example, Denise's focus group students illustrate that a teacher's best efforts to build on students' ideas and construct new knowledge with students may be seen as simply drilling and assessment. This may point to the need to be more explicit about students' roles during discussions and the role of discussions in supporting the learning of the class. My preliminary analysis of interview data also shows that as teachers use a range of strategies to manage tensions that arise during inquiry teaching, it may be important for them to balance which elements and dimensions of inquiry they attend to. However, it could very likely be that the teachers were reacting to aspects of their instructional contexts over which they had little control. For example, Sherry repeatedly emphasized in her interview data that because her students had known each other for so many years, they trusted each other to take risks during discussions and share their opinions, even if those opinions may be wrong. Sherry's strategy use may then be a reaction to her students' natural inclination towards discussion and debate.

Discussion

I began this study wanting to explore how my analytical framework describing inquiry practices as consisting of aspects of cognitive, social, and linguistic dimensions could help identify teaching tensions and characterize where teachers fell in the tradeoff spaces between elements in tension. This study extends work in the literature on teaching as managing tradeoffs by attempting to describe what it looks like in classrooms when teachers are faced with multiple, competing challenges in inquiry. My analytical framework articulates three levels of inquiry teaching: dimensions, elements, and strategies. The dimensions are the general areas that teachers need to achieve—students' reasoning about ideas in the cognitive dimension occurs as they take on new roles in discussions and use language in specific ways to talk about that reasoning. The elements, within each dimension, articulate specific challenges that may be important for teachers to attend to as they enact inquiry curricula. Depending on the particular inquiry task at hand, teachers may be in tradeoff spaces between elements within and across dimensions. Finally, the strategies give teachers suggestions for how to achieve certain elements of inquiry.

I found that by using this framework, I was able to situate the teachers at different points in the tradeoff space between elements of inquiry by doing a close analysis of the strategies they used to support students' inquiry. Furthermore, since the teachers did not use the same strategies, my analytical framework could also help articulate key points of variation between the teachers. I was able to explain some of this variation based on interview data with the teachers that revealed interesting aspects of their instructional contexts and their own attitudes towards teaching science. The interview data suggest the teachers' awareness of some of the central challenges they faced in teaching this unit: namely, eliciting students' participation, managing discussions so that students can reason with important scientific ideas, and helping students understand scientific language use.

This analysis points to the importance of having a more complex picture of teachers' practices beyond "reform" or "traditional". Through my analysis of both the patterns and the substance of classroom talk, I found that the characterization of the teacher's practice was really at the intersection of the two steps of analysis. For example, in Denise's case, it was not enough to look at *who* was doing the talking and *to whom* the talk was directed. While it was true that many of Denise's interactions looked "traditional" rather than "reform", Denise engaged students in important aspects of inquiry practices that we as curriculum designers value, such as building on students' ideas and constructing new knowledge with them. As we saw from Sherry's examples, having students simply share their ideas does not necessarily lead to collaborative knowledge-building. The teacher needs to support those knowledge-building discussions in important ways in order for productive interactions to occur. Therefore, although the classroom interactions I saw in Sherry's class initially seemed more "reform"-oriented than in Denise's class, my analytical framework lent important insight into the constructive inquiry work that both teachers were doing despite the differences in patterns of interactions that I initially observed.

Elaborating on teaching dilemmas

As I mentioned earlier, this study elaborates on previous work that describes teaching inquiry as managing dilemmas by providing a more detailed description of what it looks like in classrooms when teachers attend to multiple demands at once. To take one model of tradeoff spaces, Windschitl (2000) describes four types of dilemmas arise for teachers as they attempt to implement “constructivist” teaching into their classrooms: conceptual, pedagogical, cultural, and political. I include inquiry teaching as a category of constructivist teaching because I consider inquiry practices to be opportunities for students to generate their own knowledge about scientific ideas. Conceptual dilemmas arise as the teacher tries to make sense for herself how constructivist teaching practices coincide with or conflict with her own beliefs about teaching. Pedagogical dilemmas arise as the teacher attempts to design complex learning experiences for her students. Cultural dilemmas arise as the teacher attempts to negotiate new norms for practices with her students. Finally, political dilemmas arise as various stakeholders in school communities questions and offer resistance to new norms for teaching and learning practices. These four frames of reference for describing teaching dilemmas can also interact with each other in that a teacher’s attempts at addressing dilemmas in one frame may interact with her ability to address dilemmas in another.

I situate my framework at the intersection between Windschitl’s conceptual, pedagogical, and cultural planes. In my study, I found that as teachers design inquiry experiences for their students, they need to think about how to support students in cognitive, social, and linguistic aspects of the practices. However, this also interacts with Windschitl’s cultural frame of reference because inquiry practices represent new and often unfamiliar roles for students and teachers, ways of reasoning, and ways of using language. But in the interview data, we saw the teachers struggling with their own concepts of inquiry and how to best adapt those to their students. Denise and Sherry's enactments could represent ways in which teachers are trying to support students in unfamiliar norms for learning that arise during inquiry practices. Therefore, although Windschitl's model of teaching dilemmas outlines general frames of reference for describing the source of teaching dilemmas, my framework takes a more detailed look inside two of these frames of reference to describe teaching dilemmas and how teachers may approach those dilemmas.

This analysis also gives us some insight into the nature of teaching tensions and why they might occur. For example, the tension between *reasoning about scientific ideas* and *eliciting students' participation* makes sense if we take collaboration and public sharing of ideas to be key components of reasoning about scientific concepts (NRC, 2000). The cognitive work we ask students to do in inquiry requires challenging social interactions that are very different from traditional classroom roles. In inquiry, teachers clearly need to engage students in reasoning about scientific ideas, but if they are too directed, they risk shutting down students' exploration and construction of those ideas. However, if they allow too much exploration, they risk not being able to focus students around the important scientific ideas in the unit. In the tension between *reasoning about scientific ideas* and *understanding scientific terms*, we find another central challenge to teachers in inquiry. Public reasoning and discussion of ideas requires a common understanding of language use. My analysis highlights some of the problems that can occur if such an understanding is not present before students begin discussing their ideas. However, if the teacher is too directed in defining terms and language use for her students, they may fail to see the utility of powerful scientific terms to their reasoning.

Teaching tensions can also be the result of the students' experiences and expectations in science. For example, Denise's case highlights how the mismatch between students' and teachers' expectations within the social dimension of students' roles in inquiry practices can lead to students perceiving inquiry practices as intimidating and thus being unwilling to participate. This can lead to the teacher having difficulty eliciting participation from students and engaging them in complex reasoning tasks. The teacher therefore has the dual responsibility of introducing students to complex tasks and covering the content in the curriculum. It is no surprise that the teacher needs to find ways to balance these seemingly competing demands. In Denise's case, she created a safe space within which students could participate, thereby slowly introducing them to the practice of collaborative sensemaking. Perhaps because of this safe space, she was able to engage students in rather sophisticated reasoning about key scientific ideas in the curriculum. A teaching tension, therefore, can arise through a mismatch in expectations between students and teachers, leaving it up to the teacher to reconcile those expectations.

Sherry's students, on the other hand, were more comfortable sharing ideas with each other and using discussions to work through controversies. This was probably why there was such an emphasis in her class on the element in the social dimension of eliciting students' participation. This enthusiastic participation on the part of her students, coupled with her enthusiasm for having students experience the wonders of science, seemed to make it difficult for her to reign in lively discussions regardless of whether students were on task. For Sherry, participation was an important part of how she fostered enthusiasm in her class. Sherry wanted students to experience the excitement of discovery, discussion, and exploration but she was also aware that she needed to cover certain content ideas. She therefore used the majority of class time to have exploratory discussions with the students but then covered the content in the last few minutes in order to bring the students back to the task at hand. One can also imagine a teacher whose own perceptions of and experiences with science were more “traditional”. In this case, an inquiry curriculum might be at odds with her sense of bringing students to the “correct” answer.

This analysis also points to the importance of negotiating norms for practices as part of the supporting students in inquiry. If teaching tensions occur because of a mismatch in expectations—between students and teachers or between the teachers and the curriculum—it seems important to be explicit about these expectations. For example, if learning science as inquiry requires collaborative sensemaking, students need to be aware that this means actively participating in classroom discussions by sharing and critiquing ideas. If learning science as inquiry requires students to reason in a deep way about scientific ideas, students need to understand that this means potentially taking risks and being “wrong” in front of their peers. However, students cannot be expected to willingly engage in these new roles and take these new risks without at least some acknowledgement from the teacher that these are new types of practices. As I illustrated in this analysis, Denise attempted to engage students in complex social practices without explicitly negotiating these practices with her students. The result seemed to be a mismatch between how the students perceived Denise’s efforts during whole-class discussions and how Denise perceived her own efforts. Collaboration in science, while an important aspect of many inquiry curricula, is an unfamiliar practice to many students who are accustomed to the individualistic culture of traditional schooling. Denise attempts to make the transition to a collaborative culture without negotiating the norms for that culture with her students. Just as the cognitive and linguistic dimensions of inquiry need attending to, students cannot be expected to understand how to engage in collaborative practices by simply being given the opportunity to do so.

This negotiation of norms may also have implications for students' perceptions of science. As I illustrated from the student interview data, teachers' strategy use may have an impact on how students perceived aspects of inquiry practices. For example, even though Denise accomplished important work through her structured interactions with students, the focus group students still perceived discussions as points of assessment in which they were expected to produce the correct answer. The focus group in Sherry's class, on the other hand, perceived discussions to be forums for sharing ideas and resolving confusions. In both classes, students' perceptions may have also impacted their participation in inquiry practices.

Implications for professional development

Finally, this analysis implies possible applications for professional development. My framework may provide a way for teachers to observe their own and others' practice in order to understand which elements of inquiry they are attending to and which need perhaps more attention. In Denise's case, she may have benefited from understanding that perhaps part of her difficulty in eliciting participation from her students was that her students did not fully understand the roles they were supposed to take on during discussions. My analytical framework might allow teachers to see where the "holes" are in their support of inquiry practices. Therefore, in addition to having to understand the scientific content covered in the curriculum, teachers need an understanding of how to adapt the curriculum to their students' specific needs and, given that adaptation, how to manage dilemmas that arise between elements of inquiry. My analytical framework just begins to articulate the complexity of teachers' task as they support students in inquiry. Because this was an exploratory study of the range of practices teachers might use as they attempt to support students in inquiry practices, more work is needed to more closely link teachers' strategy use to students' perceptions of the nature of inquiry practices in order to understand how teachers can best impact these understandings.

CHAPTER FIVE:
REFLECTIONS ON THE DISCOURSE PERSPECTIVE FOR CHARACTERIZING TEACHERS' SUPPORT OF INQUIRY PRACTICES: IMPLICATIONS AND CONTRIBUTIONS

Learning science in the classroom involves children entering a new community of discourse, a new culture; the teacher is often the hard-pressed tour guide mediating between children's everyday world and the world of science.
(Driver, Asoko, Leach, Mortimer, & Scott, 1994)

Motivation for the study

The call for reform in science education is often accompanied by phrases such as "excellence and equity" in the *National Science Education Standards* (National Research Council, 1996), "science, mathematics, and technology for all students" in *Science for All Americans* (AAAS, 1990), and "empower[ing] young people to develop their scientific literacy (Driver, Newton, & Osborne, 2000) as goals for why inquiry science is an important direction for science education reform. This emphasis on equity, science for all, and empowerment of students through inquiry investigations is a powerful ideal. Because inquiry science involves students in pursuing answers to their own questions, it can be a tool for helping students learn scientific content while gaining insight into the nature of scientific processes. Students can start to see how their thinking and reasoning processes are similar to or different from those of scientists (Kuhn, 1993). Rather than merely memorizing facts and creating graphs from artificial datasets, students in inquiry science are often involved in carrying out investigations of their own design, analyzing data collected from those investigations, and constructing scientific explanations based on evidence (Schwab, 1966; Roth, McGinn, & Bowen, 1996). Having students participate actively in the process of constructing scientific knowledge is one way to teach against what Lemke (1990) calls the "mystique of science", or the myth that science is too difficult for everyday people to understand or participate in.

However, inquiry as a strategy for reaching the "excellence and equity" goals set forth in the *National Science Education Standards* (NRC, 1996) raises new challenges for students that we are only now beginning to understand. It may be problematic to assume that inquiry will necessarily lead to more equitable science (Fradd & Lee, 1999; Rodriguez, 1997; Eisenhart, Finkel & Marion, 1996). Engaging in inquiry practices such as constructing scientific explanations is challenging for both teachers and students because such practices have underlying epistemologies and norms for thinking about the world that come from the practices of scientists (Aikenhead, 1996), a community whose practices are largely unfamiliar to many students except the privileged few for whom out-of-school practices are in line with scientific practices (Cuevas, Lee, Hart, & Deaktor, 2005; Lemke, 1990). To complicate matters further, students are often expected to engage in complex, open-ended scientific practices without explicit instruction on how to do so. Researchers have argued, however, that students cannot be expected to know how to engage in such practices and roles simply by being given the opportunity to do so (Palinscar, Anderson, & David, 1993; Yackel & Cobb, 1996). For example, creating a social environment in which students feel encouraged to share their ideas is perhaps necessary but not sufficient for supporting complex inquiry practices and student-to-student interactions (O'Connor & Michaels, 1996). Researchers taking a sociocultural approach to schooling suggest that because school requires students to negotiate between the culture(s) of school and their out-of-school cultures, we need to make the norms for participation in school practices explicit to students (Delpit, 1988). As indicated in the opening quote by Driver, et al (1994) at the beginning of this paper, the teacher needs to mediate between students' everyday worlds and the culture of science that they cultivate in the classroom. Teachers play a key role in supporting students in their inquiry endeavors.

Therefore, we as a field need a better understanding of *how* teachers engage students in these complex and unfamiliar practices (Flick, 2000). Existing research on teachers' practices in enacting science education reform in classrooms frequently gives broad guidelines for how teachers should support inquiry (Engle & Conant, 2002). However, more research is needed to understand the role that teachers play in bringing inquiry to life in classrooms. Keys & Bryan (2001) argue that "Research on the roles and knowledge of teachers in implementing inquiry in the classroom will have a broad impact on science education because such studies will reflect what may be realistically accomplished on a large scale" (p. 642). Along the same lines, we as a field need more research into how teachers in inquiry classrooms are meeting the needs of diverse learners (Cuevas et al, 2001). Understanding how teachers support inquiry in diverse classrooms will help us understand better how to give all students access to the complex practices of inquiry science. Such studies will also have an impact on the design of curricular materials. If we want curricular materials to be educative for teachers (Schneider, Krajcik, & Blumenfeld, 2005)—that is, to support teachers' thinking about how to create inquiry opportunities for their students, we need to better understand what sense teachers are making of inquiry in their classrooms. This is because inquiry in the standards documents is underspecified and requires careful unpacking (Krajcik, McNeill, & Reiser, 2008) and teachers adapt new pedagogical approaches through the lense of their current understandings (Spillane, et al, 2002). I hope in this study to contribute to the growing accounts of what inquiry looks like in real-world, diverse, urban classrooms and, in doing so, provide some insight into possible implications for the design of curriculum materials to support teachers' enactments of inquiry-based science.

In this study I attempt to systematically explore how teachers operationalize the complex nature of scientific practices. I use a framework that describes inquiry as a Discourse[4] as a way to characterize the dimensions of inquiry that teachers attend to as they attempt to support students in inquiry practices. This framework, which I describe later, gave me a way to characterize how teachers may attend to multiple dimensions simultaneously and the types of support teachers may be providing even in moments that seem more teacher-directed than commonly accepted views of inquiry teaching. I define Discourse from Gee (1996) in which he argues that a Discourse community is a "social group or social network" that shares common beliefs, values, and goals. A Discourse includes not only ways of talking but also values, beliefs, and ways of interacting with the world that are used by a particular social group (Gee, 1996). As I will expand on later, inquiry as a Discourse involves students in new types of cognitive tasks, new ways of interacting with each other as they do science, and new ways of using language to talk about the science that they do. I argue in this study that these cognitive, social, and linguistic practices make up different dimensions of inquiry science that students engage in.

However, because these practices are part of a larger scientific Discourse community, there are norms for engaging in them that may or may not be familiar to students. Indeed, students' unfamiliarity with these norms may hinder their full participation in inquiry science. For example, inquiry-based curricula tend to be project-based in an "authentic" context (Krajcik et al., 1998), forcing students to take on new roles as generators of knowledge instead of merely consumers of knowledge (Brickhouse, 1994). Instead of being told by the "expert" teacher what facts they should memorize, students—through investigations they design—construct relevant

[4] This is opposed to discourse with a lower-case "d" which signifies any stretch of language. This distinction is important because I wish to emphasize the cultural demands of doing inquiry science as opposed to simply the technical demands of reading and writing science.

scientific knowledge for themselves. In the process, they learn some of the norms for argumentation and uses of evidence that are accepted by the scientific community. Consequently, inquiry poses new types of challenges for not only students but teachers as well. For example, if inquiry challenges students to engage in new norms for what counts as evidence for an argument, teachers need to support students' understandings of these norms. Therefore, it is important to understand what sense teachers make of these norms and how they attempt to support them.

Research question and analytical perspective

The goal of this study was to understand in what ways teachers do or do not make norms for inquiry practices explicit to students. In exploring this issue, I asked the question: *what is the nature of teachers' support of inquiry practices as they enact an inquiry-based curriculum*? Specifically, I hoped to understand what aspects of inquiry teachers attend to and how they do so. How and when do teachers communicate the norms for reasoning, interacting, and language use? How explicit is this communication of norms? Given that there are multiple aspects of inquiry for teachers to support at any given moment, what instructional tradeoffs arise and what strategies do teachers have to manage them?

Before I could answer these questions, however, I needed a framework for articulating different aspects of inquiry practices. As I mentioned earlier, the analytical perspective I used in this study comes from taking the perspective that inquiry science represents practices in the Discourse of science, and that these practices present challenges to students on multiple levels. Discourses are "ways of being in the world…which integrate words, acts, values, beliefs, attitudes, and social identities" (p. 127). Extending Gee's framework into inquiry science, I argue that because inquiry science attempts to approximate authentic practices of scientists, inquiry practices implicitly encompass values or norms—patterned ways of reasoning, interacting, and using language that are shared by scientists. Students come to classrooms with their own ways of reasoning, interacting, and using language that may or may not be congruent with those of scientists. Aikenhead (1996) equates the process of learning science to that of “culture acquisition” (p.5), in that there are norms for practices in the Discourse of science that may be largely unfamiliar to most students. The teacher then becomes a kind of cultural liason, helping students bridge between their own cultural practices and the subculture of science. In this study, I leverage the notion of “norms”, or patterned ways of reasoning, interacting, and using language to understand the different types of support teachers provide as they support students in inquiry science.

In this study, I argue that these norms fall into three main categories: cognitive, social, and linguistic. As students engage in inquiry practices, they learn not only new ways of reasoning about the world (cognitive elements) but also social and linguistic elements that are often imbued with epistemologies valued by science as a discipline. I call these cognitive, social, and linguistic elements of inquiry practices *dimensions* of inquiry. Although the term “cognitive” can be applied to many types of activities, in this study I limit my use of the term to apply to scientific reasoning during a particular inquiry process and reasoning about content ideas. When I characterized teachers’ support in the cognitive dimension, therefore, I saw them supporting reasoning strategies such as how to use a model to make predictions about phenomena, or connecting evidence to explanations. Another type of support I characterized in the cognitive dimension was when teachers connected scientific ideas to each other, or mapped between phenomena and scientific ideas. I define the “social” dimension of inquiry as involving the roles for teachers and students in a particular practice. For example, one way I characterized teachers providing support in the social dimension was in co-constructing an explanation where the teacher puts students in particulars role that differ dramatically from the science-teacher-as-authority role in traditional science teaching. Rather than simply answering discrete questions posed by the teacher, students need to pay attention to what is being said in order to build on each others' ideas. I characterized the social dimension of inquiry as also involving any effort the teacher made to engage students in the inherently social nature of inquiry tasks. For example, argumentation is an inherently social task in that it involves students in defending their positions *against* another. This necessarily involves students in constructing their own positions as well as being aware of other students' positions in the class. Finally, I define the linguistic dimension of inquiry as the specific ways language is used in science, whether that be how and when to use certain scientific terminology, ways to use language when analyzing data or communicating scientific ideas, or translating representations into words. For example, when I characterized teachers' support along the linguistic dimension, I noticed them explicitly or tacitly modeling how to use language scientifically to communicate about ideas. The linguistic dimension is necessarily tied to the cognitive and social dimensions, as we use language to communicate about our reasoning and to communicate with each other. However, it is a distinct dimension in my analytical framework because of the concern in the literature about how challenging it may be for students to learn science-specific norms for using language (Lemke, 1990; Halliday, 1998; Moje, 2001). As such, I expected it to be a rich dimension around which I could characterize how I saw teachers providing support for students as they engaged in inquiry practices.

In this study I argue that the norms students need to learn in order to engage in inquiry practices can be characterized in terms of these three dimensions, and that each of these dimensions represents a site where teachers might provide support. Therefore, in my analysis, I used this framework to first see if I could characterize teachers' support of students' inquiry work in all three dimensions. Specifically, I wanted to know if teachers communicated norms for inquiry practices for each of the dimensions. Did teachers' support fall into all three dimensions? If so, to what extent did they provide support in each dimension? What instructional strategies did they use to provide this support? Finally, I wanted to know how focused this support was in terms of science-specific ways of reasoning, interacting, or using language. For example, in the cognitive dimension, did teachers support generic reasoning strategies or science-specific ways of reasoning such as using evidence to support explanations? In the social dimension, did teachers support generic classroom roles and expectations for participation or science-specific roles such as critiquing explanations based on the strength of the evidence? In the linguistic dimension, did teachers support science-specific ways of using language such as specific ways to describe trends in data, or did they accept any language students used to communicate about scientific ideas?

In the remainder of the paper, I will report on two major aspects of this study. The first aspect will be to explore the major findings from the study. This section will have two parts. In part one, I will discuss the types of support I saw teachers providing in the cognitive, social, and linguistic dimensions. In the context of discussing this aspect of the work, I will also discuss possible implications for the design of curriculum materials. In part two, I will discuss the major teaching dilemma (Lampert, 1995; Sandoval & Daniszewski, 2004) I characterized using the Discourse perspective to analyze teachers' enactments.

The second aspect of the work I will discuss will be the major implications of this work for building on existing work on "doing with understanding" (Barron, et al, 1998) and border crossing (Aikenhead, 1996). In this second discussion, I will explore how the findings in my study relate to each of these areas of existing research and how this thesis makes a contribution to each.

Finding 1: Using the Discourse framework to characterize teachers' support along cognitive, social, and linguistic dimensions

In this study, I used the inquiry as a Discourse framework to analyze Denise and Sherry's enactments of the *Survive* unit in terms of cognitive, social, and linguistic dimensions. While I was able to systematically analyze how teachers were facilitating students' participation in complex knowledge-building, this analysis also raised issues about the limitations of these types of support for having students become autonomous inquiry investigators. Table 16 shows the major types of support I saw teachers providing in each dimension and the limitations of this type of support. In this section, I will discuss my analysis of the teachers' support of students' inquiry in each dimension. In exploring the nature of teachers' support in each dimension, I ask three questions:

1. Did the teachers provide support along this dimension?

2. If they did, what kind of support did they provide and what did it accomplish?

3. What are limitations in the types of support the teachers provided and what implications do these have for improving the design of teacher supports within inquiry-based science curricula?

TABLE 16: Categories of teachers' support in each dimension and issues arising from each characterization for developing students' autonomy in conducting inquiry

Dimension	Characterization of support	Limitations of support
Cognitive	Scaffolding students' participation in inquiry practices • Highlighted need for smaller reasoning steps from large inquiry practice • Identified most challenging aspects of inquiry practices:	• No explicit transitions between epistemic practices—issues for fading scaffolds • Need to be more explicit to teachers about how and when to make transitions between reasoning steps

	where did teachers get "stuck"	• Need to help teachers address more ambitious parts of the practice
	Tying lessons to general scientific principles and practices	• Only teacher-initiated; no indication that students were making connections between lessons and scientific principles
Social	Collaborative knowledge building: co-construction of complex chains of reasoning through discussions	• Co-construction of chains of reasoning is done bit by bit—students are not responsible for the entire process • Science-specific roles not emphasized during instruction
	Shifting teacher-student roles to encourage students to take more responsibility for their own learning	
Linguistic	Defining scientific terms	• No talk around *why* scientists use certain terms, or what work certain language use does for us in science
	Modeling scientific language use	

Teachers' support in the cognitive dimension

Teachers engaged students in important cognitive work of inquiry as they enacted the curriculum: they got students to reason about the relevant scientific ideas and they engaged students in substantive practices of inquiry such as providing backing for their claims, data analysis, and modeling. Indeed, most of the teachers' talk was coded into the cognitive dimension (64.1% for Denise, 72.3% for Sherry). The presence and representation of cognitive support in and of itself is not surprising, as the major work of inquiry is reasoning about scientific ideas through complex cognitive processes (NRC, 1996). However, although we know that teachers need to support students' cognitive work during inquiry, we need more elaborated characterizations of the nature of that support (Songer & Lee, 2003). In other words, what does cognitive support for inquiry practices look like in classrooms? I characterized major types of cognitive support from Denise and Sherry's enactments. In this section, I will discuss each of them and discuss how this support may have facilitated students' participation in complex inquiry practices. These were:

1. scaffolding students' participation in inquiry practices through decomposition of inquiry practices into smaller components,
2. connecting lessons to general scientific principles

These supports resulted in nuanced, elaborate support in the cognitive dimension that went beyond what was stated in the curriculum materials. To describe each of these types of support briefly, I characterized one type of support teachers provided as *scaffolding students' participation in inquiry practices*. Teachers broke down the inquiry practices into what I called *epistemic practices* and prompted students for next steps in those practices. Another type of cognitive support I found teachers providing was what I characterized as *connecting lessons to more general scientific ideas*. This was interesting given that one of the main design challenges in this curriculum was how to teach general scientific principles in a way that connected to the particular context of the curriculum (the problem of the sea lamprey invasion in Part 1 or the problem of the Galapagos Finches in Part 2) *and* gave students opportunities to generalize to scientific principles from multiple examples. I discuss each of these points in detail in the following sections.

Scaffolding students' participation in inquiry practices through decomposition of inquiry practices into smaller components

The goals for inquiry as stated in reform documents such as *The National Science Education Standards* (NRC, 1996) are broad and ambitious. More careful analysis still needs to be done in order to translate these goals into specific curriculum designs and supports for teachers. For example, one of the inquiry standards for students in grades five through eight states that students should "develop descriptions, explanations, predictions, and models using evidence" (NRC, 1996, p.145). This single inquiry standard asks students to work with many aspects of scientific reasoning: descriptions, explanations, predictions, and models. If we take just one of these, modeling, the standard is still very broad. What does it mean to "develop" a model using evidence? One can imagine building a model from scratch, having part of a model articulated and filling in the rest based on evidence, or running the model and predicting future effects based on current evidence. Although ambitious in nature, inquiry practices as described in reform documents (NRC, 1996, AAAS, 1990) leave much of the work to designers and teachers to elaborate these complex practices in order to clarify what types of reasoning are involved and to break down these practices into smaller steps that learners can understand.

Given that inquiry practices are complex and involve multiple steps, it makes sense that one type of support teachers could provide students would be to break down these complex practices into smaller, more easily grasped "steps". Additionally, it would make sense that given multiple steps in a practice, teachers might support students in complex practices by prompting them for next steps in a practice. Recent work on providing scaffolds for students in inquiry both in instruction (Scardamelia & Bereiter, 1994) and in the design of software tools to scaffold students' participation in inquiry practices (Quintana, et al, 2004; Bell & Linn, 2000; Sandoval & Reiser, 2004) include both of these types of supports as important to scaffolding students' participation in inquiry practices—breaking down a complex practice into steps and prompting students for next steps in the practice. I take as the definition of *scaffold* to be when a more knowledgeable peer assists a less knowledgeable peer in a task that would otherwise be too difficult for them to engage in by themselves (Reiser, 2004). The literature therefore provides both models for how teachers might provide this support and examples of carefully designed software tools for students to use. My analysis provides a picture of how teachers might provide scaffolds in their day-to-day enactments of inquiry practices. I describe how I found Denise and Sherry scaffolding students' participation in complex practices by both breaking the practice into smaller steps and prompting for next steps in the practice.

I use the term *epistemic practice* to describe the steps the teachers used as they broke down a complex inquiry practice into component parts. An epistemic practice is a precise description of a type of reasoning and the form around which that reasoning is done (Collins & Ferguson, 1993; Schwarz & Sherin, 2002). In contrast, an inquiry practice is a broad description of a complex learning goal. For example, in the *Survive* curriculum, lessons usually centered around a single form such as a *model*, and teachers supported several epistemic practices around that form in order to enact a complex inquiry practice such as *applying a model*. Using this analytical scheme helped to articulate the steps in reasoning teachers used to support broad inquiry practices such as *applying a model*. I found teachers to elaborate on a single inquiry practice using several epistemic practices. The result was smaller reasoning steps that the teachers used to support students' participation in complex practices.

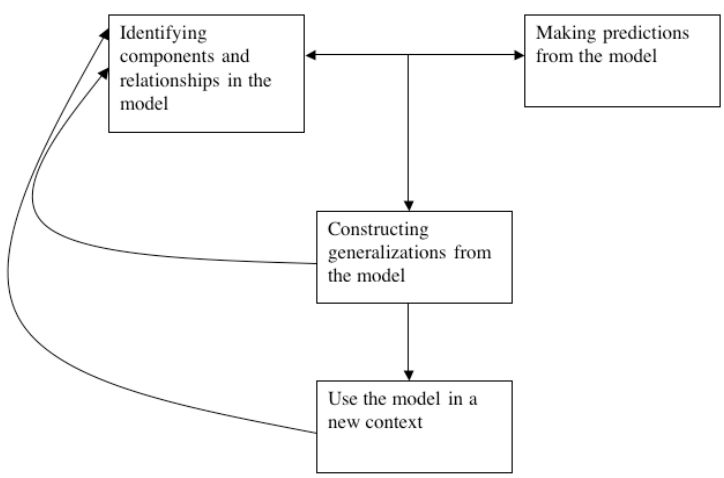
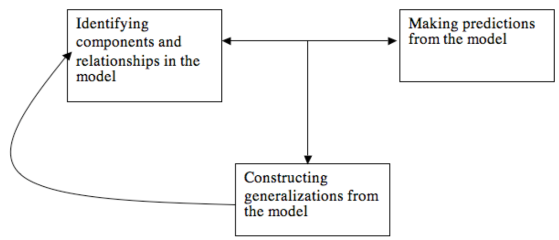
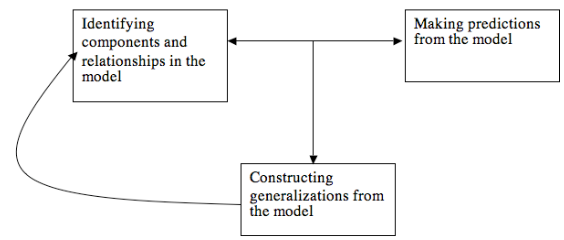
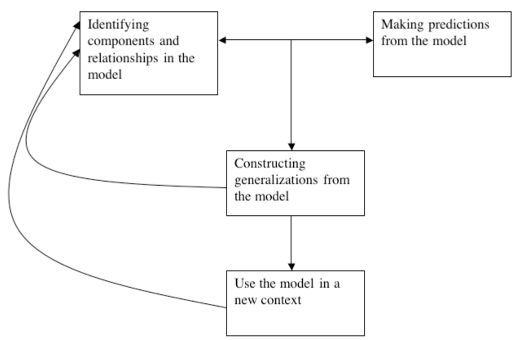
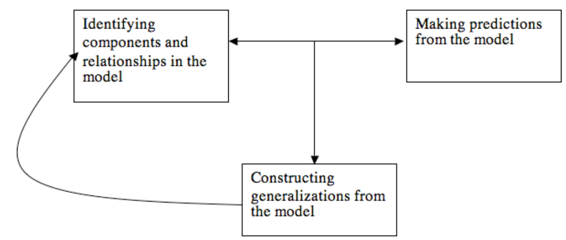


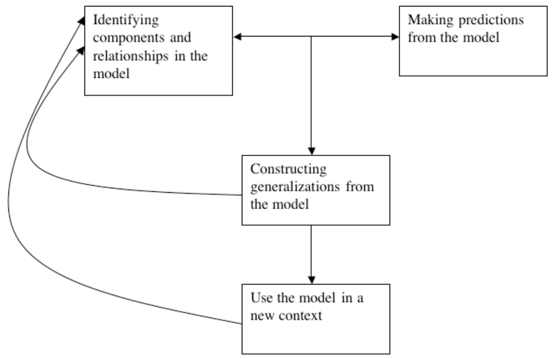
Figure 13: System of epistemic practices for applying a model.

For example, Figure 13 is a representation of the epistemic practices Denise and Sherry used to elaborate on the practice of *applying a model*. To briefly describe Figure 13, both teachers began their support of the practice of *applying a model* by identifying components within the model. This involved not only defining the parts of the model (for example, when Denise asks, “who is the producer” and what kind of things, Gina, are consumers?”) but also defining relationships between components in the model (for example, when Sherry says, “Chubs eat aquatic snails, snails eat algae.”) The next step was to perturb the model and ask students to make predictions about what would happen as a result of that perturbation. Based on these predictions, they would then construct generalizations from the model about basic principles the model was attempting to represent. The final epistemic practice was to use the model in a new context, which I only saw Denise doing. The teachers then cycled back to identifying the components of a model and asking students to make predictions based on the model.

In the *What will survive* unit, there were three lessons in which models were used to help students understand phenomena: (1) students used tools (wrench, eye dropper, spoon) to model the functions of beaks to study the relationship between structure, function, and environment; (2) students used a food web diagram as a model to understand interrelationships between species in an ecosystem, and (3) students used a computer model to understand the effect of an invasive species on population levels in a food chain. In all three lessons, both teachers engaged students in the top level of the system, the interplay between *identifying components and relationships in the model* and *making predictions from the model*. I only observed the entire system in Denise’s enactments of lessons 8 and 9. As I said above, Sherry did not engage students in the epistemic practice of *using the model in a new context* in lesson 8, and in lesson 9 she remained at the top level of the system. Table 17 summarizes the system of epistemic practices for *applying a model* that each teacher enacted for the three lessons.

TABLE 17: Systems of epistemic practices from Denise and Sherry over three lessons

Lesson number/description of model	System of epistemic practices	
	Denise	Sherry
Lesson 3: Using tools to simulate relationship between structure, function, and environment		
Lesson 8: Using a food web model to understand interrelationships between species in an ecosystem		

Lesson 9: Using a computer model to understand the effect of an invasive species on population levels in a food chain	 	

To elaborate on how one of these epistemic practices played out in the classroom, the following is an excerpt from lesson 8 of the curriculum in Sherry's class as she enacted the *identifying components of a model* epistemic practice:

Identifying components of a model

1 Sherry: Ok, so yesterday we cleared off all the desks and we made this big thing. What was the big thing?
2 Ss: food web
3 Sherry: Um, it was a food web. And Andy, what is a food web made up?
4 Andy: Um, organisms that consume other living organisms.
5 Sherry: Ok, and what would we call that if we have organisms consuming other organisms?
6 Student: Chain
7 Sherry: Food chain. So we have a bunch of food chains and they create a big web.
8 Sherry: So we have food chains connected to each other to create a food web, right? We talked about consuming, organisms, consuming, what's the beginning point of a food chain, all the way on the right?
9 Jen: producer
10 Sherry: Producer. And then other things consume it. One, one of the distinctions that was made in our reading yesterday between consumer/producer relationship and predator/prey, was something about some sort of survival. (*Sherry classroom observation, 4-22-03)*

Notice that in the *above example*, Sherry takes students through the parts of the model, labeling and defining those parts. In the original curriculum materials, the directions were as follows:

3. Remind students that they had created the Great Lakes food web in yesterday's activity. Ask students: What did we mean by the term food web? What did our food web illustrate? *Answer: A food web is composed of many interconnected food chains.*

Although the curriculum materials did ask teachers to go through this review, in the above example, Sherry went into much more detail about consumers and producers, the "starting point" of the food web, and the distinction between a food web and food chain. This practice served an important purpose: it allowed teachers to be explicit about defining parts of a model and how those parts interacted with each other. This was an important precursor to making changes in the model—for example, removing an organism from the food web—and making predictions about the results of those changes. This elaboration of inquiry practices into component practices was a way for teachers to support reasoning strategies during complex cognitive tasks. For example, the system of practices shown in Figure 1 could represent one way to understand and apply a model: first understand the components and their relationships to each other, then test your understanding by making predictions from it. Then make generalizations from that model that will apply to new contexts. Finally, use the model to make other predictions or explain other phenomena in different contexts.

The type of support that I characterize as *scaffolding student's participation in inquiry practices* is interesting because it is a way to systematically describe the ways in which the teachers went beyond what was in the curriculum materials to meet the needs of their students. It represents one vision of the teacher as "tour guide" in science (Driver, et al, 1994). If we ask students to engage in complex reasoning practices with which they are unfamiliar, an important role the teacher needs to take is helping students manage this complexity. It is useful here to reflect on the notion of *scaffolding* from the literature and how the teachers' use of epistemic practices connects to scaffolding. The "support" in scaffolding can come in many different forms. However, a key feature of any scaffolding is making the steps to a practice explicit and visible to the learner so that the learner is aware of the steps in a practice. In this way, the scaffolding can eventually cease to exist as the learner gains more facility at participating in all parts of the complex practice (McNeill, et al, 2006). In my analysis of how Denise and Sherry decomposed the practices into epistemic practices, they never explicitly stated the various reasoning steps that structured students' participation in inquiry practices. There was no meta-talk around practices, nor were there transitions between practices. Granted, the characterization of epistemic practices was an analytical perspective that I imposed on the teachers' enactments, so they never would have named the parts of the practice as *identifying* or *applying* as I did. But, the teachers never said anything like, "Before we make predictions from our model, let's first make sure we understand the parts of the model", which would have given the students a schema from which to relate future participation in inquiry practices.

To illustrate how the teachers provided scaffolding for the larger inquiry practice of *applying a model*, the following example is from Denise's class, again from the food web discussion. The example will be snippets of transcript from the discussion, separated by varying amounts of time, to illustrate how Denise took students through the system of epistemic practices shown in Figure 14.

TABLE 18: Transcript of a discussion from Denise's class

	Time code	*Transcript*	*Epistemic practice*
A	*:18 seconds*	T: Ok and what did we decide who are the producers? What kinds of things are producers? Eric: Plant, plant things T: Plant things. And what kind of things Gigi, are consumers? Gigi: the animals T: The animals are consumers. Ok.	*Identifying relationships and components in the model*
B	*3:24*	T: What happens then if the snails die and that's the chub's only source of food, what happens to the chub? Student: They'll die too T: Ok they'll die too. What happens to the lake trout then? Student: they might decrease T: They might decrease. Will they die out completely maybe? Student: they might T: Do they have other food choices? Who was a trout yesterday?	*Making predictions from the model*
C	*16:23*	T: What will happen to the rest of the organisms in the Great Lakes? What did Eddy say? Is everybody	*Constructing generalizations from the*

		affected? Students: yes T: Ok. So what happens? What happens to their populations? Larry: The prey will increase and the predators will decrease. T: Ok. Prey will increase, predators will decrease. Based on who's taken out of the system.	*model*
D	*21:25*	T: Now let's see if you really understand this. On the next page, it's asking you to make a food web using specific insects here, um, specific things. So it talks about terrestrial. What does that mean? Larry: Um, something that has to do with the earth. T: Something that has to do with the earth. So we're talking about land animals here. Or things that are on the land.	*Use the model in a new context*
E	*22:06*	T: So, Corey, what did you start with? Corey: Bears T: Bears. And where did bears go? Student: Fish T: Ok so they went to the fish. Where did that go to? Student: I didn't know what fish ate. T: You didn't know what the fish ate. Well actually in your own mind you know what the fish ate right? Student: Other fish T: Other fish? Ok. And eventually what could they eat that would at the bottom of this maybe? Student: Algae T: Algae. Ok	*Identifying relationships and components in the model*
F	*27:14*	T: So if I take something out of here what happens, you guys all know, right? Students: everything is affected T: everything's affected. Either it increases or decreases based on what I've taken out of here.	*Making predictions/constructing generalizations from the model*

In the chart above, we see Denise taking the students through a system of epistemic practices as she works with the food web model. We can see that she not only prompts them for the next step, both by asking questions and initiating new activities (as she does when she asks students to apply the model in a new context), but she also provides supports within each epistemic practice to help students engage in that practice. For example, in row B above, she is engaging students in the epistemic practice of *making predictions from the model*. What is interesting in this case is that she not only asks for an initial prediction, “What happens then if the snails die and that’s the chub’s only source of food, what happens to the chub?”, but she asks about other organisms on the same food chain. This strategy is one that she employs throughout this lesson as she takes students through this epistemic practice, and it seems to serve the purpose of having the students see how effects on one organisms have effects throughout the food web, not just at one point. She does this again in Row E.

Another example of how Denise supports the students is in row E in the chart above, where the students are applying what they have learned about relationships between organisms to a new context, the terrestrial food web. Denise asks the students to share how they constructed their food webs. When a student says she “didn’t know what fish ate”, Denise makes a direct connection back to the Great Lakes food web when she says, “Well actually in your own mind you know what the fish ate right? And the student says “other fish”. By prompting the students to remember what they learned in the original food web, Denise is able to help the student identify the same relationships in the new context. This type of scaffolding allows teachers and students to concentrate on component parts of the practice of applying a model.

If our goal in inquiry-based science education is to have students initiate and engage in complex practices, the question then remains of how useful this type of support is without explicitly making reasoning practices visible to students. If scaffolds are to eventually fade, how do students come to independently initiate important parts of the practice without knowing what those parts are? This suggests the need in the design of instructional supports for teachers to first making the important parts of practices explicit to *teachers* so that they, in turn, may make the important parts of practices visible to *students* during instruction.

In addition to articulating the reasoning steps that the teachers took students through as they supported an inquiry practice, this analysis allowed me to pinpoint where teachers got "stuck" before they reached the most ambitious parts of the practice. In Figure 1, the most challenging parts of the practice would be the bottom two epistemic practices: for students to form generalizations, or scientific principles, from the model such as, "In a food web, all species are interconnected so that a change in one species has either direct or indirect effects on all other species in the food web" and apply those principles to new ecosystems. Of course, this is an ambitious goal: to have students, through their manipulations of a model, derive sophisticated scientific principles, but it was one of our goals in this unit. The observation that both teachers spent most of their classroom time on the top two epistemic practices, *identifying* and *making predictions*, was not disheartening; making predictions from a model after first identifying the important parts of that model and how they work together is challenging and requires certain dexterity with the model. This implies that the teachers recognized a certain need to give their students opportunities to manipulate and make predictions from the model and indicates the complexity of the model with which they were working. However, it also indicates a site where perhaps more supports were needed in the curriculum materials to support teachers in reaching the more ambitious parts of the practice.

Connecting lessons to general scientific principles

One of the main challenges faced by the designers of the *Survive* curriculum was the conceptual structure of the curriculum. The lessons were designed in pairs, in which the first lesson in the pair was designed to teach students about a general scientific principle (such as food web interactions or structure/function relationships) and the second lesson in the pair was designed to have students apply that scientific principle to the curricular context (the sea lamprey invasion or the Galapagos Finch investigation). Table 19 shows the lesson pairs in the first half of the curriculum. The design team wanted to give students concrete experiences with each of the scientific principles, but this was at the risk of students getting confused about how the concrete examples in the first lesson related to the following lesson in the pair. For example, students in lesson 3 conducted a “birds and beaks” simulation in which they used different-shaped “beaks” (tools or utensils) in different “environments” to see which beak was most suited to catch food in which environment. The lesson was meant to give students concrete experience with the scientific principle of structure and function relationships. In the next lesson, students conducted observations of external and internal structures of specimens of yellow perch and sea lamprey and learned about the functions of those structures. The challenge was how to get students to make the conceptual connection between the structure/function relationships they experienced in lesson 3 and the structures and possible functions of the yellow perch and sea lamprey in lesson 4.

Here I saw the teachers providing key cognitive support to help students make connections between scientific ideas in the unit. This type of support, which I named “making connections to students’ ideas” was present in every lesson that I analyzed for each teacher. Table 20 shows an overview of how this type of support was represented in the lessons that I analyzed. One important methodological note to mention here is that even though table 20 shows the number of utterances coded for this type of support for each teacher, the utterance varied in length. For example, within the twelve utterances coded for Sherry in lesson 3, some consisted of one sentence connections she made between students’ ideas and relevant scientific ideas. In contrast, the one utterance coded for Denise in lesson 3 was an utterance consisting of seven turns at talk between Denise and her students to jointly construct how the simulation they had conducted related to the relevant scientific principle.

TABLE 19: Pairs of lessons in the first half of the *Survive* curriculum

Lesson	*Activity & Context*	*Scientific principle*
1	Reading & discussion: Introduction to invasive species, introduction of the driving question	Effects of invasive species on native species
2	Reading and mapping: Background on sea lamprey invasion	N/A
3	Simulation: Birds and beaks	Structure/function
4	Observation/dissection: Yellow perch and sea lamprey	
5	Reading & discussion: Patterns of reproduction in elephants, oak trees, mosquitoes, Giant Tortoises, and dandelions	“long” and “short”-life reproducers
6	Reading & discussion: Patterns of reproduction in sea lamprey	
7	Simulation: Introduction to food chains and food webs: terrestrial and lake food chains and food webs	Food chains and food webs; direct and indirect relationships
8	Simulation & discussion: Great Lakes food web; sea lamprey effects	
9	NetLogo simulation: grass, rabbits, and snakes, & invader	Population-level effects of invader
10	Data analysis: trout, whitefish, chub, and sea lamprey population data	

11	Answering the driving question	All of the above

TABLE 20: Number of utterances coded for each teacher for *making connections to students' ideas* by lesson number

Lesson number	Denise	Sherry
3	1	12
5	2	8
8	4	3
9	2	3
10	3	8

To provide a flavor of this type of support, the following is an example of how Sherry made the connection for the students between lessons 9 and 10. In this pair of lessons, students first ran a computer simulation in lesson 9 that traced the population of levels of grass, rabbits, and snakes in a mini-ecosystem. Students could then add an invader to the ecosystem and observe the resulting population levels of the three main organisms. In lesson 10, students looked at actual population data from the Great Lakes of three species of fish that were most affected by the sea lamprey invasion. Students analyzed the data in terms of pre- and post-invasion population levels and then constructed explanations for those levels. The two lessons were analogous both conceptually, in that they both involved looking at population levels before and after and invader, and in terms of representations, in that they both involved the use of line graphs that traced population levels over time. In the next example, we see Sherry highlighting both of these connections between the two lessons:

40 Sherry: Then what we did, **we took what we saw in Net Logo and we got to bring it back to these [shows population graphs] and look at what really happened in a situation.** What we just did was NetLogo with the food chain of trout, whitefish, chub. And then we introduced that invasive species of the sea lamprey and got to see what happened.

41 Jen: Ooooh it's like the same thing!

42 Sherry: It's exactly what we just did. Ok? It took a long time to do it, but it's exactly what we just did. **We just said, so what we did was we got our data [puts population graphs on the overhead] this is like our little graph at the bottom of net LOGO and we got to see what happened. And we didn't have—remember how we didn't introduce the invasive species right away? Boom. Comes in, what happens to the populations, and then we look at it over generations.** That's exactly what we just did. (*Sherry class observation 5-12-03)*

In this example Sherry draws connections between introducing the invasive species in the NetLogo simulation and the introduction of the sea lamprey in the actual data. This revelation is not lost on Jen when she says, "Ooooh, it's like the same thing!". Sherry also makes the connection for students between representations—that the output of the NetLogo simulation, which was a line graph that traced population levels over time, looked very much like the population data students analyzed in lesson 10. Notice, however, that this is coming from Sherry—that the teacher is doing the work to connect the two lessons conceptually, not the students. Indeed, in all of the documented cases of this type of support, the connections between students' ideas and relevant scientific concepts was always initiated by the teacher. Ideally we would want students to make these conceptual connections, to be able to generalize from one case to another, and to be aware of the scientific principles at play at any given moment in the curriculum. We want students to not only relate specific cases together—as in relating the Netlogo simulation to the data analysis lesson, but to generalize from several cases to complex scientific principles.

As I said before, students in this unit needed to use what they learned in the first lesson in the pair to make sense of the investigation in the second lesson in the pair. There is preliminary data that indicates that students were taking up these concepts in a way that was more general than the specific contexts in which they were embedded in a lesson. For example, immediately following the excerpt shown above, the following discussion occurred:

43 Sherry: If we add any other organism to this [food web], if it's introduced, is it going to affect this food web?
44 Ss: Yes
45 Jackie: I think it depends on the qualities it has. If it has like the sea lamprey
46 Sherry: Ok
47 Jackie: that you know, depends on more big fish
48 Sherry: Ok. What if it depends on little fish? Is it going to affect…
49 Ss: Yeah
50 Sherry: Do you guys remember when we did these chains? Are they affected whatever size they are? Does it affect something?
51 Becky: Look when you add the sea lamprey it affected a whole lot of stuff. If you were to do another one…
52 Sherry: Ok.
53 Jackie: Yeah it affects one, it affects everybody else.
54 Sherry: Overall everything. And it may not just be the aquatic food web. Is it going to affect the terrestrial?
55 Ss: Probably
56 Sherry: Possibly. It certainly affects us. Right? It affects us whether it's financial or otherwise. Yes ma'am.
57 Jen: So what you're basically saying is that it can affect it directly and indirectly. (*Sherry classroom observation, 5-12-03)*

In this example, Sherry begins to generalize to other examples of introduced species, and we can start to see sophisticated reasoning on the part of the students. In line 320, Jackie responds to

Sherry's question with "it depends on the qualities it has". This indicates that she is thinking that the effect that an introduced organism would have on a food web depends on its "qualities", presumably meaning what it eats. This indicates that Jackie understands that not every organism effects the food web in the same way, and that what an organism preys on will determine the first effect it has on the food web.

We cannot, however, expect students to automatically do this for themselves. This type of cognitive support is important in lengthy inquiry investigations in which students may not see the connection between day-to-day lessons and the overall driving question of the unit (Barron, et al 1998). Relating scientific ideas to each other and to one's own ideas is challenging, and much work has been done to design software environments to prompt students to do this during inquiry investigations (Bell, Davis, & Linn, 1995; White & Frederiksen, 1998;) The findings in this study give us an idea of how a teacher might support students' first efforts at making connections between lessons and relevant scientific ideas. The ideal would be to have students work toward making these connections for themselves. White and Frederiksen (1998) give us a model of what this might look like in their reflective assessments that teachers would engage students in. They found that students who engaged in these reflective assessments scored higher on final projects and had greater understandings of engaging in inquiry. Together with the findings from this study, I argue that teachers may need to very explicitly make these connections for students in their first efforts and then move towards more self-initiated self assessment as they become more practiced at engaging in inquiry practice.

Teachers' support in the social dimension

In this study, I define the "social" dimension of inquiry as involving the roles for teachers and students in a particular practice. I could characterize aspects of Denise and Sherry's enactments as support in the social dimension when they engaged students in actively participating in knowledge-building discussions, asked students to provide complex answers that advanced the scientific discussions of the class, and when they encouraged students to take more active roles in their own and others' learning. Instances in which I characterized the teachers' support as social occurred during whole-class knowledge-building discussions and when students worked in small groups.

I saw the teachers supporting the social dimension of inquiry by eliciting participation from their students in different ways and for different purposes. In Denise's case, she used social supports to build complex chains of reasoning with her students. She struggled with getting students to participate in whole-class discussions (personal conversations, 2-27-03. 4-21-03, 5-9-03) and so she asked sometimes very directed questions to elicit that participation. But she was able to have students reason through evidence-based explanations through these discussions. In Sherry's case, I saw her eliciting participation to get multiple ideas on the table for the same question. This is in contrast to traditional images of science in which there is only one "right" answer to a question. Therefore, both teachers appeared to be supporting the social dimension to support the scientific thinking in their classrooms. This resulted in students collaboratively knowledge-building either with each other or with the teacher, sharing their ideas in a safe environment.

For example, Denise used structured questions during discussions to push students to articulate their ideas and co-constructed complex chains of reasoning with students. In this way, students took on roles during discussions as active participants and active knowledge-builders rather than passive listeners. Denise used very directed questions during discussions, which had the result of minimizing the "risk" of participation during discussions for students, thereby distributing the responsibility for providing complex answers among several students, not just one. Take, for example, the excerpt below:

139 Denise: Ok. Now let's think about it. When the sea lamprey comes in, it likes the trout so you think that will go down.
140 Denise: Ok? So if one of its—if one of the trout's food is the chub, what's going to happen to them at first?
141 Larry: Go up
142 Denise: It's going to go up because?
143 Eddy: There are no predators.
144 Denise: There's no—one of its—
145 Larry: Less predators—for the moment
146 Denise: less predators, they're going to go up for the moment, for the moment they're going to go up and then what's going to happen?
147 S: Sea lamprey eats it
148 Denise: Well then the sea lamprey gets done with the lake trout. Now are we talking you know, days here, are we talking years?
149 Ss: Years
150 Denise: Years. Ok. We're talking long periods of time. We're not talking, you know, this week it ate the lake trout, next week it ate that. No, we're talking years that this happened. And it happened slowly. It didn't happen all at once. Ok. So, what are we going to say about the chubs at first? For a moment it went?
151 Eddy: It went up
152 Denise: and then it?
153 S: Went down
154 Denise: And what's our evidence?
155 Eddy: The sea lamprey finished hunting the trout.
156 Denise: Ok but for the moment it went up because one of its predators was…
157 Eddy: was gone
158 Denise: was gone. And then the sea lamprey turned on it. Ok. (*Denise class observation 3-18-03)*

I characterize the support Denise provides in this example as social support because she co-constructs a chain of reasoning with students about what will happen to first the trout, then the chub, after the sea lamprey is introduced into the Great Lakes. Rather than simply telling students the answer or being satisfied with a simple prediction as Larry provides in line 121, she pushes students, through her sometimes very directed questions, to construct a complex prediction that includes a chain of reasoning grounded in evidence. Therefore, in order to do the cognitive work of forming a prediction, the social dimension also emerges as an important site for support. Notice that Denise could have just given the answer herself, but this type of exchange indicates the importance she is placing on having students participate and thus take more responsibility for their own learning.

From interview data with Denise, we can start to see her concern for supporting the social dimension of inquiry. The following are two excerpts from interviews with Denise, one from the pre-interview and one from the post-interview. Each shows evidence of the importance Denise placed on supporting the social dimension:

Excerpt from pre-interview with Denise:

34 Denise: I'm trying to call on them more. You know, I'm trying to pick out—you know, some of them are just like hiding from me all the time. I'm trying to make them answer me. (*Denise pre-interview, 3-5-03)*

Excerpt from post-interview with Denise:

58 CTT: How did this unit meet your goals for inquiry?

59 Denise:: I think I successfully, I think it successfully trained, I call it train the kids to take charge of their learning. To have expectations and to follow through with them and to back it up with—I used to call it, now I call it, you're going into high school, it has to be, your 8th grade stuff instead of 1 sentence and they'll all look at me and say oh, I can't just say yes and ok. Although I did see that on a lot of the tests but **verbally they're starting to talk, give me reason. And that successfully, them taking charge of it, I've seen it.** I

> mean, I can't tell you how many kids have you know, running up to me, this is what I learned, this is what I saw…But that's what I want. You know, what if we did this. And I'm getting a lot of that instead of these oh god 40 minutes let's hope it's over. *(Denise post-interview, 6-4-03)*

In the first interview excerpt, we can see Denise struggling with how to elicit participation among her students by calling on them. She characterizes the lack of participation as students "hiding from me all the time". This was a problem Denise faced throughout much of the unit and she shared this concern with me several times during the enactment (*personal communication, 3-24-03, 4-22-03, & 5-9-03)*. In her post-interview, Denise is pleased that she has seen evidence of students "taking charge" of their learning when "verbally they're starting to talk, give me reason. And that successfully, them taking charge of it, I've seen it".

Therefore, in classroom observations, we are able to see evidence of Denise eliciting complex reasoning from her students at the same time that she supports the social dimension of inquiry. From interview data we can start to see that the cognitive and social dimensions are present and not unrelated to her. She sees the social interaction as being a way for students to take responsibility for their own reasoning. Notice, however, that although Denise is able to get students to reason through the chain of events, she is the one making the conceptual connections for the students and asking very structured questions to elicit their participation. Students contribute to the knowledge-building in discrete "pieces", adding only what Denise asks for. There is no indication of whether students could do this complex cognitive work on their own, because I saw no instances in which this type of complex knowledge-building was initiated by the students.

Therefore, although Denise is able to elicit participation in whole-group discussion, and she is able to heavily structure those discussions so that she moves the class toward complex meaning-making, it is an open question of what roles, if any, the students thought they were playing in these discussions. Denise does not engage students in any discussion about science-specific roles. We can contrast this conversation with those that Herrenkohl, et al (1999) found, in which there were specific “sociocognitive” or “audience” roles for students during discussions, such as checking predictions and theories, summarizing results, and assessing the relations between predictions, theories, and results. In these conversations, teachers explicitly supported students in science-specific roles for students during discussions. For example, the teachers said, “Remember, your job specifically is to get them to say their predictions and theories.” (Herrenkohl, et al, 1999). Herrenkohl, et al found that these explicit prompts for scientific roles to elicit predictions, theories, and results resulted in more student-initiated questioning and examining of theories and evidence. These results indicate the importance of being explicit to both teachers and students about roles in discussions. In much of the design work in science education, supports for cognitive reasoning are at the fore of the design effort (Krajcik, et al, 1998; Reiser et al, 2001). What the findings from Herrenkohl, et al’s and my study indicate is the importance of providing these supports in order to get to the more discipline-specific social supports to as a way to enhance students’ collaborative reasoning about scientific ideas. This may be especially important for teachers who do not have much experience teaching science as inquiry, or who do not have the inquiry-specific pedagogical content knowledge (Shulman, 1994) to support students’ learning through social interactions. Teachers may have general strategies for eliciting participation from students, but these strategies may not necessarily translate into discipline-specific ways of supporting collaborative reasoning like consensus building and critique of scientific ideas. In Denise's case, there is no talk about alternative claims or evidence, what makes certain evidence good to back up certain claims, what the link is between the evidence and a claim. All of these more science-specific prompts would have represented more dramatic shifts in students' roles and would have possibly gotten students to participate in the discussion in a more *scientific* way.

Similarly, we can use Herrenkohl, et al's (1999) findings to reflect on discussions in Sherry's class. As I said earlier, Sherry was very successful at eliciting participation from her students. However, she took no credit for the ease with which this occurred. In her post-interview she says:

71 CTT: I guess my question is just what kind of learning do you think happens in your whole-group discussions?
72 Sherry: I think the lightbulbs happen. I think there's a lot more learning going on than when I'm lecturing. When I lecture they're like, "oh yeah". That's when the doodles really come.
73 CTT: Well what do you think it is about those discussions that differ from lectures that help them learn?
74 Sherry: They're more animated. I think they tend to listen to their counterparts more than me. I know in this class they trust each other a lot more than most other classes. This class was more willing to take risks and say stuff….You could see it in groups.
75 CTT: Do you think that's anything—that trust. Do you think there's anything you did to support that?
76 Sherry: No. This is a group that's been together—we talked about this before. This is not me. This is the example of what parents and continuity does for kids…Everyone but one kid went on this class trip. You know what I mean?...And I think that trust was—I think it gets built. There are probably moments when it's been picked up by me. But I won't take credit for that. I think it was there coming in and anything that got added was able to be added because of who they were. (*Sherry post-interview, 6-11-03)*

In this excerpt we can see how Sherry attributed the kinds of interactions that occurred during discussions to the trust that had been established between the students even before they entered her classroom. We can see through this interview data that Sherry places great value on whole-class discussions when she says, "I think they tend to listen to their counterparts more than me. I know in this class they trust each other a lot more than most other classes. This class was more willing to take risks and say stuff." Therefore, eliciting participation from her students was not a challenge that Sherry faced. In fact, her students also seemed to see the value in the whole-class discussions. In the following example, one focus-group student, Kevin, explains how whole-class discussions help work out confusions:

81 CTT: So when you guys get confused like that in class, how do you guys usually figure stuff like that out?
82 Kevin: We just start talking.
83 CTT: Just start talking.
84 Kevin: Yeah.
85 CTT: Why is that helpful?
86 Kevin: Because we can hear other peoples' thoughts how we should do this and pick the best one.
87 CTT: Ok so do you think, so when you hear other peoples' thoughts, do they help you understand things better?
88 Kevin: Yeah
89 CTT: How?
90 Kevin: because we were talking about the, in the later lesson about the food chain and stuff like that and the direct and indirect and we talked about that and I feel we got it.
91 CTT: So why was that helpful to talk it out?
92 Kevin: We learned it better than how she explained it. We got the explanation better and clearer for us.

We can see in line 92 how Kevin sees the value in hearing his peers' ideas because they can "learn it better than how she [Sherry] explained it." Therefore, Kevin is saying that sometimes the explanations he hears and constructs with his peers is more understandable than the one that comes from the teacher. This echoes what Sherry says in line 74 above: "I think they tend to listen to their counterparts more than me." The other focus-group students expressed similar sentiments about whole-group discussions in Sherry's class. Clearly, Sherry has fostered a social environment in her class that we would, in theory, find ideal: both the teachers and students feel comfortable participating in discussions and—most importantly—they see the *value* in listening to each others' ideas.

However, eliciting participation in general is different from having students engage in complex knowledge-building discussions. Sherry's discussions often did involve almost every student in the class, but she often failed to bring out the big ideas from the discussions. I found that Sherry fielded responses from almost every student whenever she asked students to share their results or their ideas, but these were generic prompts for participation rather than science-specific prompts for playing a certain scientific role. Consider the following example:

33 Sherry: Monique what did you have?
34 Monique: They would stay the same.
35 Sherry: You said it would stay the same why?
36 Monique: Because the chub has one less predator because the lake trout is being eaten and it also has the sea lamprey eating it.
37 Sherry: Anybody else have anything? Jen what did you guys have?
38 Jen: we put decrease
39 Sherry: Why?
40 Jen: Because the chub has other predators besides the lake trout and the sea lamprey so it's kind of getting the double whammy too with its other predators and the sea lamprey. And since the sea lamprey's um an invasive species, there's more eating the sea lamprey—I mean eating the chub.
41 Sherry: Did everybody get that?…Um anybody have that chub will go up? Why Sam?
42 Sam: I said because um, the sea lamprey is going to eat more of the lake trout because it's the biggest fish, and so it will have more time to reproduce.
43 Sherry: Ok. Anybody else?
44 Anna: We put that the population will first go up and then it will go down.
45 Sherry: Why?
46 Anna: Because it also has whitefish as the predator… and then it will go down when the sea lamprey eats it
47 Sherry: Ok so it will go up because it loses its predator the lake trout the assumption is that the sea lamprey is eating all the trout and not paying attention to the chub, right?
48 Students: Yeah
49 Sherry: And then when the trout is gone it will all go after the chub…Ok, anybody have anything else you want to add about chub? (*Sherry class observation, 5-12-03)*

In this example, Sherry fields many answers to the question, “what will happen to the chub (a type of fish in the Great Lakes) once the sea lamprey (an invasive species) is introduced?”. Students are using as a source of evidence a complex food web of the Great Lakes. In this discussion, Sherry accomplishes two important things through her interactions with the students. The first is that she is pushing the students to provide backing for their claims. We can see this from her repeated use of the prompt “why”, which I will discuss in the next section. The second is allowing many ideas to be brought up as answers to the original question. The effect is that multiple ideas—each with different backings—are introduced during the discussion, thus setting the potential for rich discussion about the merits of each backing, which claim is the best one based on the available evidence, etc. But as we see in this discussion, Sherry never brings the class to that level.

This pattern of eliciting multiple responses to the same question was typical for Sherry and not just isolated to the above example. In fact, in the five lessons that I coded (lessons 3, 5, 8, 9, and 10), each lesson contained at least one knowledge-building discussion in which students either made predictions at the beginning of the lesson, discussed the work that they did in the lesson, or both. These discussions ranged in topic from discussing structure/function relationships, patterns of reproduction, food web relationships, population fluctuations, and the effect of the sea lamprey on populations in the Great Lakes (as in the example above). Typically students worked in groups before coming together for whole-class discussions, and Sherry would typically hear from each group to get their contributions rather than trying to organize the talk around the ideas that emerged. In each of these discussions, Sherry showed the same pattern for eliciting participation from her students: fielding responses from each group or pair of students (depending on how she had students working collaboratively within each lesson). This left little time at the end of each lesson to critically discuss the strengths and limitations of each response in relation to the relevant scientific principles at play in the lessons. In addition, because this pattern of eliciting multiple responses did not leave time for consensus-building around a common conclusion, thus leaving little for students to build on for future work. The other effect of this practice was that Sherry had less time in general to proceed through the unit. In fact, Denise and Sherry began the *Survive* unit on the same day, and in roughly equivalent numbers of instructional days (Sherry: 36 days, Denise: 38 days), Denise was able to complete the entire unit while Sherry completed half of the unit.

Returning to Herrenkohl, et al's (1999) notion of sociocognitive roles for students to play, we can see that in Sherry's discussions, as in Denise's discussions, prompts for participation are not science-specific. While students are clearly expected to participate and provide backing for their claims, they are not responsible for examining each others' claims or the backing to those claims, or relating claims to each other to see similarities and differences between those claims. Therefore, while both teachers stressed the importance of students' participation in knowledge-building discussion (for example, when Denise says, "Eddy, what was your prediction, what did you say?"), this participation was limited to, in Denise's case, *any* participation and in Sherry's case, providing claims with backings. Social interactions were not set up in these classes for *scientific* discussions of comparing claims and their backings, or arguing for the best claim based on available evidence, or linking students' predictions to results and scientific principles. This is interesting given the emphasis in the literature on the importance of participating in social contexts that mediate students' cognitive activity (O'Connor & Michaels, 1996; Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002). O'Connor and Michaels (1996) argue that

> facility in particular types of complex thinking follows from repeated experience in taking on various roles and stances within recurring social contexts that support those types of intellectual give-and-take and its proto-forms (p. 64).

Therefore, intellectual engagement (and, hopefully, learning) with scientific ideas should emerge from repeatedly engaging students in social contexts in which they are asked to share and critique each others' ideas and participate in scientific discourse.

Driver, et al (1994) similarly argue that if we view knowledge construction in science as a social endeavor, we need to give students access to the cultural tools of science through interaction with more knowledgeable others. Students can then appropriate these tools for their own use and understand how and when to use them. They argue that "the teacher's intervention is essential, both to provide appropriate experiential evidence and to make the cultural tools and conventions of the science community available to students" (p.7). Therefore, a major challenge we have is to both give students access to cultural tools of science, such as designing investigations, argumentation, and interpretation and use of evidence at the same time we support their meta-understanding of the norms for using these tools. From this analysis, however, I saw no evidence of the students' appropriating such tools for themselves even though they were the major goal of the curriculum. As I discussed above, the teachers' support in the social dimension was focused on getting students to participation generally rather than having meta-discussions on how to participate *scientifically* in the social construction of scientific knowledge.

My analysis suggests the need to support teachers in understanding the importance of discipline-specific roles in science classrooms, and for more explicit supports in curriculum materials for those roles. Teachers need to understand the difference between the roles students play in, for example, a brainstorming discussion versus the roles students play when they share their final explanations, and the differences in each. While the *Survive* curriculum gave students many opportunities to engage with each other in small-group work and whole-class discussions, these opportunities did not fully achieve their intended purpose (of getting students to critically examine each others' ideas through discussion and argumentation). One reason for this could be that both the curriculum materials and the teachers were not explicit enough about *which* roles students should play during these social interactions and *how* these roles should play out in small group work and whole-class discussions. This suggests the need for explicitly defining roles for students and having teachers understand the critical job those roles play in engaging with both the scientific content and the scientific reasoning processes of the class.

Teachers' support in the linguistic dimension

It is through language that the *doing* of science occurs. As Lemke (1990) puts it, "'Talking science' does not simply mean talking *about* science. It means *doing* science through the medium of language." However, if the language of science is imbued with epistemological commitments and values with which many students are unfamiliar, the language may also represent a significant challenge to the doing of science. In this study, I therefore hypothesized that teachers would spend time supporting students in how to use language to accomplish the important cognitive and social tasks of inquiry, and that I would be able to observe clear instances in which teachers explicitly distinguished scientific ways of using language from everyday ways of using language.

What I found was that, as in their support along the social dimension, the teachers' support of the linguistic aspect of inquiry practices was not as explicit as I expected given the existing literature on the complexity of scientific language use in both the talk in classrooms and in curricula (Lemke, 1990, Rosebery, Warren, & Conant, 1992). I characterized teachers' support in the linguistic dimensions in three categories, each of which I will describe in more detail in this section:

1. defining scientific terms
2. modeling scientific language use
3. using discourse markers to prompt students for next steps in inquiry practices

I found that the teachers' support along the linguistic dimension was mainly focused on defining scientific terms, or struggling to define them through whole-class discussions. Because disciplines in science have very specific ways of using language, we cannot underestimate the importance of having a shared understanding of terms for doing important cognitive work. Moje, et al (2001) called all of the students in their study "science language learners", because they were all learning the specialized ways of using language and the values associated with those ways of those language uses. Moje et al point to the challenge in both teaching and curriculum development of merging students' everyday ways of using language with science-specific language. Indeed, how scientific language is used to describe phenomena can be very different from students' everyday uses of language (Reif & Larkin, 1991; Lemke, 1990; Rosebery, Warren, & Conant, 1992). Lemke (1990) argues that "a large part of the job of science education…is to provide students with new ways of talking about scientific topics" (p.27). Herrenkohl et al (1999) found that teachers needed to begin knowledge-building discussions by defining key terms like *theory* in order to get students to reason with those terms. It makes sense, therefore, that students would need a shared understanding of scientific terms before being able to use those terms productively to reason about evidence or argue about claims. There were instances of teachers defining terms for students in all lessons for Denise's class and all but one lesson for Sherry's class. As we saw in Sherry's discussion about "stable" and "unstable" populations, having an understanding of appropriate ways for using language was important for the class as a whole to make progress on reasoning about ideas and data:

> 277 Sherry: Sammy says his, the snakes, invasive species, and grass were pretty stable.
> 278 Jen: Meaning stable, like was it straight?
> 279 Sammy: No the lines were going to the same spot.
> 279 Jen: You mean unstable like increase and then decrease?
> 280 Sherry: Stable as in you pretty much see similar patterns as it's going. There are some peaks, there are some declines, but they're pretty stable. (*Sherry classroom observation, 5-12-03)*

In this example, Jen is trying to make sense of the words "stable" and "unstable" in the context of a whole-class discussion because Sherry never explicitly defined these terms for the class. She draws on what are supposedly her own notions of what "stable" and "unstable" mean: *straight* (line 275) and *increase and then decrease* (line 277). The actual definition of stable, which Sherry attempts to articulate in line 278, actually includes Jen's intuitive notion of **un**stable (increase and then decrease). This discussion, which lasted an entire class period (45 minutes), ended with the students being frustrated that they couldn't come to consensus around a definition of the terms:

> 58 Sandy: everybody's looking at stable different
> 59 Sherry: So we're looking at pattern, we're looking at—like some people might look at this and go whoa, that's totally unstable, and other people might go well, that's clearly stable, there's an increase— (*Sherry classroom observation, 5-12-03)*

Lines 318 and 319 illustrate both the students' and Sherry's realization that "everybody's looking at stable differently" and that students were talking past each other during most of this discussion. It points to the teaching challenge that even though students are talking and arguing, they may not be arguing about the right things. In this discussion, students were arguing about their ideas, but they were really arguing because they did not understand from which definition of “stable” and “unstable” the others were working. Of course, the important part of the discussion was not what “stable” and “unstable” meant, but the reasons behind those patterns in the data. However, the students were never able to get to that part of the discussion because they could never come to a consensus about how to use these particular terms. This is similar to the pattern of not coming to consensus around students’ predictions or conclusions. Allowing multiple ideas to be on the table needs to be accompanied by consensus-building and culling of those ideas so that students leave these discussions with important scientific concepts in hand.

This discussion highlights the struggle that students may have when attempting to use complex scientific terms in the context of inquiry investigations. Because of the social norms in Sherry’s classroom (see discussion in previous section), these types of confusion were easily surfaced and discussed. However, if these social norms are not established in classrooms, or if teachers are not as in tune to their students’ need for linguistic support (as Denise was), these confusions may remain below the surface and interfere with complex cognitive inquiry work.

Notice, however, that there is no talk about *why* this might be a difficult term to define, or how the term “stable” might be defined differently in this case than in students’ everyday uses of the term. This suggests that in the design of curriculum materials, the use of complex scientific language as a way to get students to engage deeply with scientific ideas or processes requires some mapping between the term and its specific use in the context of the investigation. Languages are social constructs, imbued with the values and intentions of its users (Hicks, 1996). We need to make these values and intentions clear to students, especially as they appropriate someone else’s language (that of scientists) in inquiry to communicate about the science that they are doing.

Another form of linguistic support I saw teachers providing was modeling their expectations for scientific language use. This took place either in the form of (1) the teachers using scientific language in appropriate ways but not being explicit about norms for that language use, and (2) being explicit about how their expectations for scientific language use. The first instance of modeling scientific language use occurred in every lesson for both teachers. Below are three instances of this modeling from one observation in Denise's class:

> Eric: some of them go down.
> Denise: Some of them go down. Can we be specific about who goes down?

> Denise: What's on the X-axis?
> Larry: Time period
> Denise: Time period in what?

> Denise: It's unstable but is it decreasing, increasing…
> Student: Increaseing
> Denise: Is it slowly increasing?
> Student: greatly increasing
> Denise: Greatly increasing. Ok, so—
> Student: Dramatic
> Denise: Dramatically increasing. Ok. So between 1944 to 1963 I'm going to say, I'm going to put major—you can use whatever descriptive word you want.
> *(Denise class observation 3-18-03)*

As we can see from these examples, Denise is calling the language use out as a focal point in instances when students are asked to describe something either orally or in writing. This focus is separate from the other dimensions because she is focusing on *how* they express their reasoning rather than the reasoning itself. While these two processes are linked—the teacher has no idea of the type of reasoning separate from the language the student uses to describe that reasoning, these examples call out instances in which the student is able to communicate his or her reasoning in ways that somehow do not meet Denise's expectations for the specificity of language use.

The second way of modeling scientific language use was actually only observed once in the data in Denise's class, but it stands out as an instance of a teacher having a meta-discussion with their students about the norms for engaging in a linguistic practice:

316 Denise: No, you can't do that! No! You can't say, here's my evidence. You gotta say, "specifically on chart number 1, on this line, shows this". You can't just say well here it is, I'm too lazy, I want to go on spring break! [Ss cheer] [Denise laughs] So. Somebody else.
317 Mike: I put that matings are decided only on the number of spots but not the length of the tail. Because right here on the surviving males, one of the peacocks had a length of 121 but only had 5 matings but the one that had the most matings only had 113 tail but most matings had the most number of spots.
318 Denise: Now see? He gave me evidence. He gave me a conclusion, he gave me some evidence, he went to the chart. Your group gets the A for the day. [clapping] (*Denise class observation, 4-10-03)*

In this example, I see Denise providing support in the linguistic dimension by modeling the level of specificity of language that she expects as students cite evidence for a claim. Notice that she not only communicates her expectation that students have conclusions backed up with evidence, but that the evidence be (1) from "the chart", and (2) specifically cited, down to the particular *line*. This represents the most explicit linguistic support I found in my analysis. However, Denise never discusses why it is important to use such specific language when citing evidence. Furthermore, Denise seemed so focused on getting students to provide *any* evidence for their claims that she did not delve deeper into the more substantive parts of the practice. Therefore, although she is fairly explicit about *how* she wants data referenced, there is no discussion about the sufficiency of the evidence or the appropriateness of the evidence for the students' claims. This suggests the need in curriculum materials to support teachers in having meta-discussions about terms like “evidence” and “conclusion” and how to evaluate and critique them. This is especially important in situations similar to Denise’s class in which many students are learning English at the same time that they are learning how to use scientific language to communicate their ideas.

The final way in which inquiry practices include linguistic aspects is in a more general discourse sense. For example, language can code for complex behavior, as we saw with Sherry’s use of the discourse marker *why* to prompt students to provide reasoning for a claim (see chapter 3, this dissertation). The use of this subtle cue is met with success in this case, as Sherry is able to get students to provide reasoning for their claims. However, being able to successfully engage in inquiry science in classrooms depends not only on understanding the language of science in written and represented forms, but also being able to, as Lemke (1990) puts it, “find the science in the dialogue” (p.11). In other words, students and teachers are constantly engaged in dialogue that may or may not contain important scientific information about the task at hand. This subtle use of the discourse marker to communicate the norm for providing reasoning for a claim can be potentially confusing for students as it does not make the practice visible to students. Having a linguistic perspective on this discussion allows us to see how subtle the cues can be for students in following the flow of information in a scientific dialogue. Students need to be able to decode these cues as norms for participation, something that may be very challenging for students who are unfamiliar with the scientific practice, the activity system of the classroom, or the language of science (Lemke, 1990). From an epistemological standpoint language can also code for particular attitudes about making claims in science. By constantly asking “why” after someone makes a claim, Sherry models the attitude in science that claims should not be accepted without some kind of backing for those claims.

Finally, my analysis of teachers' support in the linguistic dimension also raises the question of how teachers serve as interpreters of language, both in terms of interpreting the language of science to students, and tying students' language back to formal scientific ways of using language. While I provided examples of teachers interpreting the language of science into ways students could understand, teachers also need to be constantly aware of how students' more informal talk may reflect complex understandings of formal scientific concepts (Hammer, 1997). In other words, when a student says something like

> I put that matings are decided only on the number of spots but not the length of the tail. Because right here on the surviving males, one of the peacocks had a length of 121 but only had 5 matings but the one that had the most matings only had 113 tail but most matings had the most number of spots. *(Denise class observation, 4-10-03)*

teachers, too, need to "find the science" in the talk. For example, in the above excerpt, a teacher would need to see how the student made a claim in the first sentence and then, as evidence, compared two contrasting pieces of data. Therefore, just as students need mapping between their own intuitive ways of communicating and those of science, teachers need to be able recognize the ways in which students' talk maps on to the important cognitive work we ask them to engage in.

In addition to the three types of linguistic support I described in this section, I saw additional aspects of linguistic support that I describe in more detail elsewhere (this dissertation, papers 2 and 3). These included translating representations in language to unpack the information that is often condensed in complex scientific representations, explicitly defining processes like making hypotheses, making predictions, etc. (this is in contrast to defining scientific terms, described above), and pushing students to be more detailed in their descriptions of data. The frequencies of each of these are shown in table K below. The distribution of each category of support is different in each lesson. However, this makes sense given the nature of the lesson. For example, lesson 10 was the only lesson in which I saw teachers pushing students for more detailed descriptions of data. However, this was the only lesson of the five lessons I analyzed in which the students were looking at actual data and were asked to describe it in detail. Less important than the distribution of categories is the presence of some type of linguistic support in each lesson that I analyzed. This indicates that the support of scientific ways of using language was an important part of how these teachers supported students in inquiry, but further study is needed to understand best practices for supporting scientific language use in classrooms, how students take up this language, and the effect of understanding language use on learning and engaging in scientific content and practices.

TABLE 21: Other linguistic categories of support

	Denise					Sherry				
Lesson #	3	5	8	9	10	3	5	8	9	10
Translating Representations	0	0	1	11	13	0	0	3	4	6
Defining processes	0	3	2	0	4	8	2	7	2	9
Detailed descriptions of data	0	0	0	0	4	0	0	0	0	2

Support in the linguistic dimension was thus found for both teachers in all lessons that were studied. This focus on the *language use*, apart from the cognitive or social aspects of the task, was striking in that it highlighted the importance of both definitional aspects of scientific language use and communicative aspects: in order to successfully participate in science, one needs to not only have an understanding of how certain terms are used, but one must be able to express one's thinking in ways the convey the appropriate level of specificity. The interesting aspect of teachers' support in this dimension was that although both teachers attended to this dimension, there was no meta-talk around why there are specific expectations for language use in science, or how it is different from everyday uses of language—apart from the single example from Denise.

Finding 2: Articulating tradeoff spaces between elements of inquiry

The work in this study extends earlier work on tradeoffs and managing dilemmas by presenting an analytical framework for not only identifying the tradeoffs that arise as teachers enact inquiry curricula but also for describing how teachers deal with these tradeoffs. I use my analytical framework that I developed in earlier work and explore how it helps identify teaching tensions and where teachers are in the tradeoff space between them. I explore the possibility that teaching dilemmas arise when teachers attend to aspects of inquiry practices not only within the cognitive, social, and linguistic dimensions but across dimensions as well. For example, when a teacher attends to social aspects of inquiry such as making sure all students' ideas are heard, does this come at the expense of aspects in the cognitive dimension such as coming to consensus around key scientific ideas? This is important for both curriculum designers and teacher educators in order to better support teachers—through curriculum materials and professional development opportunities—in understanding the types of difficult pedagogical decisions that might arise as they enact inquiry curricula. For example, recent research into teachers' enactments of inquiry-based curricula in both mathematics and science suggests that teaching is more accurately described as managing dilemmas and working within tradeoff spaces rather than making clear-cut decisions (Lampert, 1995; Ball, 1993; Hammer, 1997; Windschitl, 2002, Sandoval & Daniszewski, 2004). What we as a field still need, however, is more detailed descriptions of what it looks like in classrooms when teachers are in tradeoff spaces between different aspects of inquiry. How do teachers attend to multiple demands of inquiry? Are the teachers aware of the tradeoff spaces within which they seem to be working? What strategies do they use?

This analysis identified a key tension in teaching inquiry science: wanting to have students reason deeply about important scientific ideas, but having that reasoning initiated by the students instead of the teacher. This tradeoff, between the elements of reasoning about scientific ideas in the cognitive dimension and eliciting students' participation in the social dimension, highlights one of the major challenges in teaching science as inquiry and relates to my perspective of inquiry as a Discourse. As I said earlier, in inquiry we often ask students to engage in new types of social interaction, such as publicly exploring, discussing, and arguing about ideas in the context of whole-class and small-group discussion. In the context of the individualistic nature of schooling and the "mistake stigma", or the fear of making mistakes (Herrenkohl, et al, 1999) that many students have, this public sharing of ideas can be intimidating. Therefore, a key challenge in inquiry is getting students to reason publicly in a deep way about scientific ideas. My analysis not only identified this as one of the key tensions that Denise and Sherry faced, but I was able to characterize the tradeoff space between these two aspects of inquiry. A representation of this space is shown in Figure 14.

To briefly describe the tradeoff space shown in Figure 14, within the cognitive element of reasoning about scientific ideas, teachers can achieve more or less convergence around key ideas that are most relevant to the task at hand. In the social element of eliciting students' participation, teachers can elicit more or less structured interactions. Denise had very structured interactions with her students that limited the space of ideas that could be brought up during discussions. However, she was able to get students to reason about the ideas that were relevant and important to the tasks at hand. Sherry, on the other hand, was able to elicit a variety of responses to questions she asked and being very non-evaluative in her responses to students' answers. This had the effect of putting many ideas up for consideration during discussions, but left little class time to come to consensus around important ideas of the unit.

There is also an interaction between the elements. As one has less structured interactions in the social dimension, this opens the discussions to more ideas being considered, but if the teacher does not mediate and focus students on the most important ideas, the result could be less convergence on the relevant ideas in the lesson. As one has more structured interactions in the social dimension, this might lead to a more limited discussion space, but it also might lead to more convergence on important ideas in the cognitive dimension.

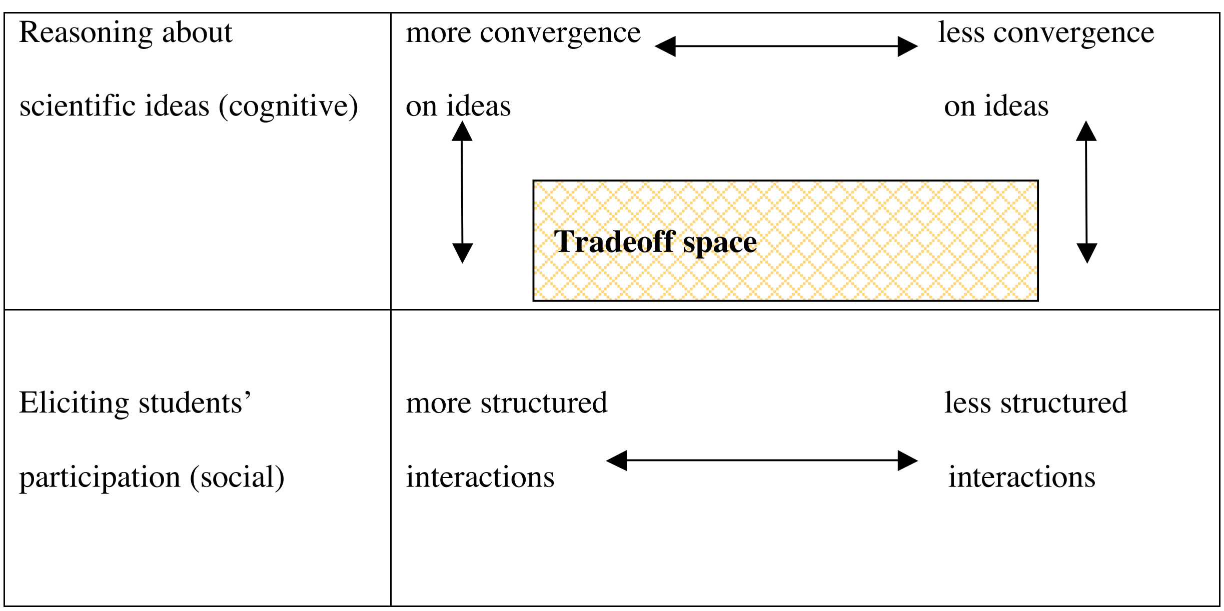


Figure 14: Mapping out the tradeoff space between two elements of inquiry

What is interesting about this space is what happens in the range of practices between the extremes. Given that inquiry teaching can be realized in multiple ways across diverse instructional contexts (Songer, et al, 2003), this analysis looked at two teachers situated at different points in the tradeoff space between the same elements of inquiry. Although we know that there are a range of instructional practices that can exist between the extremes of the tradeoff space, comparing the two teachers begins to give us actual accounts of what those practices might look like. In the literature on managing tradeoffs in both inquiry science and teaching mathematics for understanding, much work has been done to identify some of the major tradeoffs that teachers face (Lampert, 1995, Sandoval & Daniszewski, 2004; Hammer, 1997; Windschitl, 2002). My study contributes to this intellectual space in articulating the work that teachers do within tradeoff spaces and gives an analytical perspective for looking at what happens in those spaces between extremes of practice. Although we still need more accounts of real inquiry teaching in more contexts (Songer, et al, 2003), these types of studies have implications for the design of curriculum materials and professional development opportunities for teachers.

First, by articulating the decisions teachers need to make at key points in inquiry practices, we may be able to prepare teachers with (a) the range of decisions they might make at key points, (b) strengths and weaknesses of those decisions, and (c) strategies for handling those decisions. Teachers can observe video “vignettes” of different approaches to managing key teaching tradeoffs, with analyses of key cognitive, social, and linguistic aspects that each vignette brings to the fore. In so doing, we begin to articulate the “problems of teaching practice” (Lampert, 1995) that teachers might face in reform science, and work towards helping teachers manage those problems.

Discussion: Implications and contributions

In this section, I will discuss three areas where I see this work making a contribution to existing literature:

1) The Discourse framework was able to account for the teachers' practice as they enacted the unit. The teachers' support of inquiry could be characterized in terms of cognitive, social, and linguistic dimensions.
2) The teachers' use of general prompts in the social and linguistic dimensions points to the difficulty of supporting discipline-specific practices in inquiry and "doing with understanding"
3) The tacit nature of teachers' support for inquiry practices in all three dimensions points to challenges for "border crossing" between students' out-of-school understandings and the more formal practices of science.

The importance of supporting inquiry along the cognitive, social, and linguistic dimensions

The starting point for this study was the development of the inquiry as a Discourse framework in which I hypothesized that I would be able to characterize teachers' support of inquiry into three dimensions: cognitive, social, and linguistic. One could certainly argue that because I began with these dimensions, it is no surprise that I found the teachers' support along all three dimensions (see Figure 16). However, beginning with the framework did not preclude the possibility that I would not find any support along one or more of the dimensions. While I certainly expected to see the majority of the teachers' support along the cognitive dimension (and this is, in fact, what I found), I was not at all sure if I would find social and linguistic support, or that I would be able to characterize these types of support in any meaningful way. What I found was that not only was I able to characterize teachers' support in meaningful ways in each dimension, but I was able to describe how teachers both supported multiple dimensions simultaneously (see this dissertation, Chapter 3) and the tradeoff spaces between multiple dimensions in which supporting one dimension came at a cost of supporting another (see dissertation, chapter 4).

As Figure 16 indicates, the majority of the support moves I saw the teachers making were cognitive moves. This indicates a focus in science teaching on the content and on how to engage in "authentic" scientific methods such as collection and analysis of data, and understanding complex representations such as models. However, to truly engage students in rich social interactions around science learning takes sophisticated pedagogical content knowledge in inquiry science around how best to facilitate those social interactions to be the most productive for science learning. When teachers do not have sophisticated facility with this kind of pedagogical content knowledge, we may see practice like we saw in Sherry's case where the eliciting participation was the extent of the whole-group social interactions. Similarly, teachers need to be facile with the language of science in order to build bridges between the ways in which students use language and scientific ways of using language.

However, in interview data with the teachers, I could see how the teachers were at least concerned with going beyond the cognitive dimension in their support of inquiry. For example, both Sherry and Denise talked about linguistic challenges that occurred during the unit and how they tried to support students through those challenges. This concern for the linguistic dimension was different for each teacher—for Denise, it was concern with the students learning English as a second language, and with Sherry, it was concern that the scientific terms were getting in the way of students being able to communicate their reasoning. Below are two excerpts from the teachers' post-interviews that illustrate this point:

Excerpt from Sherry's post-interview:

93 CTT: What do you think were your students' biggest challenges?

94 Sherry: The biggest challenges. Um, [T leafs through the student workbook]…Biggest challenges for my kids. Structure/function/environment.

95 CTT: Why do you think that was such a huge…

96 Sherry: It's the wording. I think you might see it on some of the tests. I know they know what they were talking about but they can't word it to give me the answer. There's something about the wording about it that totally fucks with them. I wrote in here "clarify structure and functions". All we ever talked about was mouth. And we might need to talk about, you know, there are many different functions. What is the purpose of a foot, you know. Um, but it was the wording. Because they could say, "if you have a sucker, then you gotta have something that you can suck". Totally could get that but…

97 CTT: How did you help them through that?

98 Sherry: Actually, we got a really good answer. I wrote the answer down that somebody gave. [T reads from the book] "An environment's food resources need to match an organism's structures' function to ensure survival." And I wrote two different possibilities for this wording. "How is an organism's structure and its function impacted by the environment it is in?" Um "How is an organism's ability to survive determined by its feeding structure, function, and environment?" (*Sherry post-interview, 6-11-03)*

Excerpt from Denise's post-interview:

60 Denise: And I think they get it more when they've explored it first before they actually have to get the standard definition. I think they need to know those standard definitions especially being the ESL kids that we have. And I think that's where I needed to focus a

little bit more on, to make sure they understood the language. You know, the language of the science. And I don't believe I did that through this unit. I think I lost a lot through that.

61 CTT: So what do you mean the language of the science?

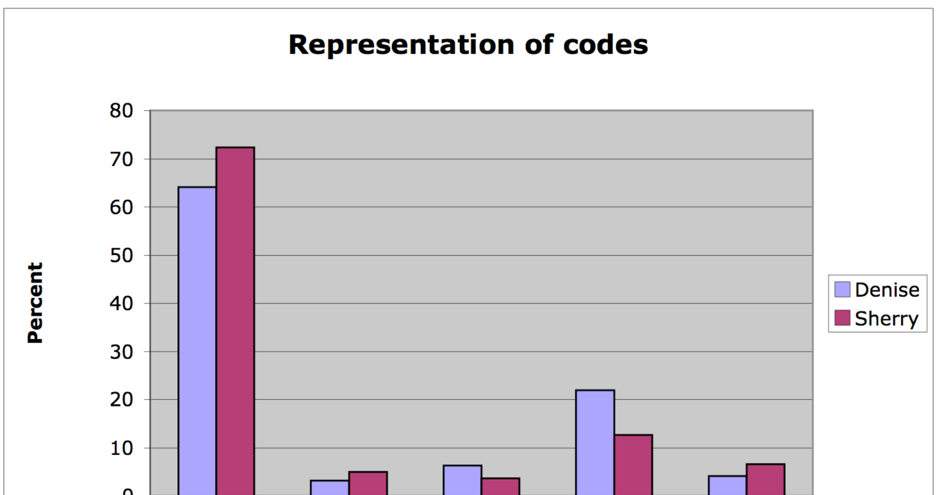
62 Denise: Well maybe 95% of these kids are bilingual and science is a whole other language that they have to learn. And I needed to step back lots of times and focus on, you know, ok, well what, like natural selection, even though they explored it, I need to go keep going back to it and re-talking about it and re-visiting it and re-teaching it. Because for kids with second language problems, it takes them 10-15 times before it sinks in. They can't just hear it once or twice and I've learned that working here for a few years.

63 …

64 CTT: How do you think science as a language is different from maybe other things that they're used to?

65 Denise: They need it broken down. Um, when you say natural selection to them, they're like, "ok, so you naturally select something". Yes, but how does that happen? Well natural means to them well it comes from the ground somewhere. You know, I mean, those are the kinds of issues I need to be aware of teaching this kind of kid is I need to know where their baseline is. They've got the standard definition—maybe. Even the stuff length, width and height, it's tough for them. They didn't understand—ok, so length is long. *(Denise post-interview, 6-4-03)*

Sherry's interview data, together with the findings described in the previous section, indicate the importance of the linguistic dimension as a *separate* dimension. In Sherry's excerpt above, she says, "I know they [the students] know what they were talking about but they can't word it to give me the answer." In other words, students were able to communicate their reasoning in terms *other* than those asked for in the unit, but the students had trouble when Sherry asked them to communicate their answer in terms of structure, function, and environment. Denise's interview data indicates the relationship between the actual scientific term and students' prior understandings of those terms. She talks about how important it is to have students explore—through the investigations in the unit—the concepts and then giving them the definitions. In other words, she likes to give students the opportunity to reason with the concepts before giving them the actual terms for those concepts. She says, "when you say natural selection to them, they're like, 'ok, so you naturally select something'." Therefore, the term "natural selection" can interfere with the reasoning that students have already done through the investigations, and Denise tries to support students learning "standard definitions" of those terms as a way to support the linguistic dimension of inquiry.



	Cognitive	Social	Linguistic	Cog/Soc	Cog/Ling
Denise	64.1	3.1	6.3	21.9	4.08
Sherry	72.3	4.9	3.6	12.6	6.5

Figure 15: Representation of dimensions for Denise and Sherry in the data

These findings indicate the importance of designing curriculum materials that help teachers support students in more than the cognitive dimension of inquiry. While the reasoning processes are clearly an important aspect of the design of any inquiry learning environment, the findings from this study indicate that teachers may be concerned with linguistic and social aspects of the inquiry learning environment that may be tacitly assumed but never explicitly supported in inquiry materials. For example, when we ask teachers to support students' understanding of concepts such as "natural selection" or "structure and function", we as designers need to think carefully about both how we want students reasoning about these concepts and the ways in which we think students should communicate about these concepts. We need to think carefully about how we word questions to students and how teachers might support students' prior understandings of those terms. Furthermore, we need better ways to actually get at students' prior understandings of these terms. We assume that students will come to an understanding of these complex scientific terms by simply being engaged in authentic scientific practices—however, these findings indicate that linguistic supports need to be explicitly attended to rather than treated as if they are unproblematic and do not interact with students' prior understandings and experience.

Doing with understanding

My analysis of teachers' support in all three dimensions points to a common theme in the literature about the challenge of supporting inquiry in classrooms: what Barron, et al (1998) call the distinction between "doing" and "doing with understanding". The teachers in this study did, indeed, get students to engage in complex reasoning, forming predictions based on evidence, and analysis of complex data. These were important goals in the *Survive* unit and the inquiry as a Discourse perspective gives us a way to empirically analyze how complex it is to support students in these endeavors. However, my finding that the most elaborate and science-specific support came in the cognitive dimension suggests the challenge of getting students to "do" a cognitive task versus getting students to really engage in the scientific practices associated with those tasks. For example, students engaged in whole-class discussions in which they shared their ideas and were pushed by the teachers to back up their claims with evidence. There was no talk about what made a *better* claim, or what was the *best* evidence to back up a claim. As I said earlier, I began this study expecting to see explicit support in each of the dimensions, such as meta discussions with students about what evidence means, or how one would construct and explanation where claims were backed up by evidence or reasoning. I hypothesized that the linguistic and social dimensions would be avenues by which the teachers could have these reflective discussions with students about norms for reasoning in science. The absence of these types of discussions indicates the challenge of not only getting students to participate in complex practices—or "doing"—but also getting them to understand *why* they participate in these practices in certain ways and what intellectual work these practices do for you—the "doing with understanding".

An implication, therefore, of this work on the notion of doing with understanding is helping teachers design reflective moments during instruction to be explicit about how to engage deeply with scientific practices. Barron, et al (1998) argue for four design principles that are important in facilitating doing with understanding: (1) defining learning-appropriate goals that lead to deep understanding, (2) providing scaffolds such as contrasting cases, (3) giving multiple opportunities to self-assessment and revision, and (4) developing social structures that promote participation and a sense of agency. The *Survive* curriculum materials, while having students engage with a driving question that motivated learning important scientific principles like structure/function relationships, food web interactions, and influence of environment on population fluctuations, did not give students opportunities to evaluate how well they had learned these concepts. The students needed to submit a “plan” at the end of the unit in which they were to utilize all of the principles they had learned during the unit, but there was no opportunity for reflection, comparing plans to each other, or having students critique each others’ plans. Doing so would have set up opportunities for students to engage deeply with the scientific ideas in ways that went beyond simply participating in inquiry practices. It would have set up opportunities for teachers to be explicit about what it meant to “apply” principles like structure/function relationships to a concrete plan, and would have set up social structures to facilitate critique and comparison.

Clearly, how a teacher enacts any curriculum is dependent on many complex, interconnected factors, not the least of which is teachers’ perceptions of their students’ familiarity with the practices and content within that curriculum. Lee and Fradd (1999) found that teachers enacting inquiry science curricula with diverse learners had assumptions about the best way to support students’ first efforts at engaging with inquiry, especially when students were also learning English at the same time. These approaches tended towards the “explicit” model of instruction in which teachers “tell and direct as they point out important information and review key concepts” (p.15). While this approach to teaching science and inquiry has not been viewed positively in the literature, researchers advocating for more egalitarian learning environments have argued for explicit teaching of norms for participation for students who are unfamiliar with these norms (Delpit, 1988). The challenge, therefore, is to go beyond this explicit teaching to give students opportunities to appropriate practices for themselves and “learn how to learn” (Brown et al, 1993) instead of simply “learn how to participate”. My findings that Denise and Sherry mainly focused on getting students to participate may well have represented the current state of understanding and focus for both the teachers and students in terms of inquiry efforts. In her interviews, Denise voiced her concern about her students' unfamiliarity with English and with scientific practices, and this may have been why we saw such structured support in her enactments. From interviews with Sherry, she indicated her focus on having all students participate and maintaining students' enthusiasm for science. Both of these cases may represent cases of teachers are focused on participation do not yet have the time to move beyond that to address deeper issues of domain-specific understanding and participation in complex practices. More work needs to be done to explore the range of teaching practices that are possible within inquiry environments and how to integrate explicit instruction with more exploratory approaches to give students autonomy while at the same time providing learning environments in which all students have access to the norms for participation (Fradd & Lee, 1999).

Border crossing into the subculture of science

I began this work with the premise that inquiry practices embody underlying epistemologies that are unfamiliar to students and thus present barriers to their successful participation. Here I reflect on Aikenhead's (1996) characterization of learning science as "border crossing" from students' own "subculture" into the "subculture of science". Aikenhead defines "culture" as "the norms, values, beliefs, expectations, and conventional actions of a group" (p.8). According to this definition, inquiry science fulfills the definition of a culture: there are norms for practices that encompass the values, beliefs, expectations, and conventional actions of a group of people—scientists. However, students come from many subcultures that may be defined by their age, peer groups, ethnicity, and gender. All of these subcultures have their own norms for action that may be very different from those of scientists. Therefore, learning science can be conceptualized as crossing the border between a student's culture(s) and that of science. In order to make this border crossing, however, students need help. Indeed, just as their peers help them understand "rules" for participating in games and play, students need help from teachers and curriculum materials for understanding the norms for participating in scientific inquiry practices. Students cannot be expected to intuitively know these norms simply by being exposed to engaging investigative contexts or curriculum materials (Herrenkohl, et al, 1999). However, inquiry investigations often immerse students in investigations without explicit support for how to use the scientific tools of inquiry to engage in those investigations.

In this study I hypothesized that teachers might attempt to facilitate this "border crossing" by communicating rules for inquiry practices in three dimensions: cognitive, social, and linguistic. The challenge for teachers is how to provide support in all three dimensions for a single practice. For example, students are often told to critique each others' work without being taught explicitly on which criteria they should evaluate one's work, how to apply those criteria to the investigation at hand, and how to give suggestions for future directions. Simply knowing the definition of the term "evidence" does not mean that the student knows how to critique the strength of one's evidence in relation to one's claim, or how to give suggestions for what evidence would make one's argument stronger. Therefore, support in the cognitive task of critiquing another's claim needs to be coupled with support in the linguistic dimension of what terms like "critique" and "evidence mean. Students also may need support in understanding what their roles might be in such a conversation—to provide criticism on the basis of one's claims and evidence rather than on a personal basis.

However, the support the teachers in this study gave was seldom explicitly stated. I began this study expecting to find explicit support in each of these dimensions. What I found, instead, were mainly tacit cues that teachers used to communicate complex norms within each dimension. This raises some important issues in considering how to support students in inquiry practices. For example, if students are rarely explicitly taught how to engage in a practice, how and when do they learn the norms for engaging in that practice? How can explicit instruction be built into curricular materials for both teachers and students? What would this explicit instruction look like?

This has implications in terms of how to make practices visible to teachers and students. Much work has been done in providing scaffolds and technology-based tools to make important aspects of inquiry practices visible to students (Bell & Linn, 2000; Sandoval & Reiser, 2004; McNeill et al, 2006; White & Frederiksen, 1998). This work focuses on providing prompts for students at opportune times as they engage in complex practices such as argumentation (Bell & Linn, 2000), constructing scientific explanations (Sandoval & Reiser, 2004; McNeill et al, 2006), and keeping track of their progress (White & Frederiksen, 1998). However, assuming that teachers are key players in making practices visible to students during classroom instruction, the current study raises questions about how to make norms for practices visible to teachers so that they, in turn, can make those practices visible to students during instruction. Davis & Krajcik (2005) argue that

> Teachers must know how to help students understand the authentic activities of a discipline, the ways knowledge is developed in a particular field, and the beliefs that represent sophisticated understanding of how the field works (p. 6)

and that educative curriculum materials can serve this role. They outline nine design heuristics to inform the design of educative curriculum materials for teachers. An example heuristic is number 7, which states

> Curriculum materials should provide clear recommendations for how to support students in making sense of data and generating explanations based on evidence they have collected and justified by scientific principles they have learned. The supports should include rationales for why engaging students in explanation is important in scientific inquiry and why these particular approaches for doing so are scientifically and pedagogically appropriate.

My analysis points to a way to think about how to “provide clear recommendations for how to support students in making sense of data”, etc. by breaking the practice down into cognitive, social, and linguistic aspects. For example, one recommendation for supporting students in making sense of data might be that we need to help them translate the data from its representational form to language that students understand, a linguistic support that I saw Denise and Sherry implementing. Another recommendation based on my analysis would be to model how evidence is to be used to support a claim, a linguistic and cognitive support I saw Denise implementing. One implication from my analysis, therefore, are specific suggestions for supporting cognitive, social, and linguistic aspects of inquiry practices that can be incorporated into the design of educative curriculum materials for teachers so that the practices themselves can become more visible to them.

Implications for future research

This study suggests future work that could be done to explore implications of the inquiry as a Discourse lens to other contexts. For example, it would be interesting to study students’ everyday encounters with inquiry or scientific practices to see how they engage in these practices outside of the classroom. Nasir, Rosebery, Warren, and Lee (2006) argue for a cultural view of learning that privileges the repertoires of practice (Gutiérrez & Rogoff, 2003) in which students participate rather than a list of practices that we want all students to engage in. In the specific case of science learning, this means expanding our notions of what it means to engage in science in classrooms. Nasir, et al (2006) cite research that documents intersections of children's everyday reasoning in science with those of scientists. The challenge is therefore to give students opportunities to engage in science in ways that are congruent with their everyday practices while still engaging students in rigorous and complex scientific reasoning in classrooms. By applying my framework to look at students' everyday repertoires of practice around science, therefore, one could ask: what are the social practices children engage in around a cognitive task like analyzing data or information and what language do they use to do so? What are the everyday ways in which students engage in argumentation, what social roles do they play when they do so, and what language do they use? How are these cognitive, social, and linguistic ways of doing science different or similar to what we are asking students to do in classrooms? Can we use students' everyday ways of making sense around science to make practices more meaningful to them beyond a superficial content level by connecting activity structures (social) or ways of using language (linguistic) to the complex cognitive tasks of inquiry?

Admittedly, I began this study expecting to see students engaged in authentic scientific practices that approximated those of scientists. Taking the notion of a Discourse into the classroom seemed to be a challenge, but one that I thought I would see teachers tackling in their enactments of the curriculum through discussions of social roles and scientific language use in the context of "authentic" cognitive work. What I see now is what has been discussed before—that existing student, teacher, classroom, and school cultures intersect with curriculum materials in important ways that we need to better understand in order to understand what types of scientific Discourses can be constructed in schools. Denise and Sherry each represent a case of how inquiry can be enacted in classrooms in particular contexts. As Brown, et al (1993) ask, “What should constitute authentic activity in the classroom?” (p.190). To that I would also add, “*Who* should constitute the authentic activity in the classroom?” To change the Discourse of science in classrooms, we need systematic, empirical ways to take into account the multiple, overlapping influences of what students and teachers bring into classrooms.

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APPENDIX A: LESSON 8, FOOD WEBS

LESSON #8: FOOD WEBS

Overview: *In the previous lesson, students learned about relationships between different organisms by constructing food chains. In this lesson, they will investigate how the Great Lakes environment is composed of several food chains that together constitute a food web. Using their basic knowledge of food chains, they will construct and develop the larger and complex food webs. Through this activity, they will recognize and identify the different relationships that exist between organisms. They will investigate how organisms are interconnected by their interactions with each other. In addition, they will seek to define the roles that each individual organism has in its environment. This lesson concludes with student predictions of how the Great Lakes will be affected if or when one organism is removed or added from the existing food web.*

	Learning Objectives	**Assessment Criteria**
1	Students will be able to describe the relationships that exist between organisms within an environment.	Students' descriptions include the classification of organisms by their diet and by their interaction with other organisms.
2	Students will be able to describe the interdependence of and survival of organisms within an environment.	Students' descriptions include hypotheses and inferences regarding the consequences of change in food sources.

<u>Benchmarks</u>:

5A5: **All organisms**, including the human species, **are part of and depend** on two main **interconnected global food webs. One includes microscopic <u>aquatic</u>** [ocean] **plants, the animals that feed on them, and finally the animals that feed on those animals. The other web includes land** plants**, the animals that feed on them, and so forth.**

5D2: **Two types of organisms may interact in several ways: They may be in producer/consumer, predator/prey,** or parasite/host **relationship**. Or one organism may scavenge or decompose another. **Relationships may be competitive** or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other.

<u>Preparation</u>:

Time: Two 40-minute class periods

Materials:

<u>Day One:</u>

Balls of Yarn (at least five different colors)

Colored chalk

Great Lakes In-Class Reading

Great Lakes Note Cards (containing organism name, locale, and food source)

Teacher Preparation Note: Copy and cut out the Great Lakes Cards (one card per student). You may want to glue the cards on index cards or heavy paper to facilitate their use in future classes. Punch a hole and insert a string through the card so that students can wear these cards as organism tags. This will free up student hands to hold onto the yarn throughout the activity.
Each color of the yarn represents a different food chain. As this activity continues the students will have created a large web with all the different colors of yarn. After the activity the students are asked to drop the strings they are holding. The result is a large tangled mess of multi-colored yarn. Please note that the yarn is dispensable and cannot be used for multiple classes.

Day Two:
Food Web Overhead Sheet
Overhead projector

Instructional Sequence:

Day One

Introducing the lesson (10 minutes):

1. Review the homework from the night before.

2. Remind students about the food chains they created in the previous lesson.

Ask students: What did each of your food chains represent? *Answer: The feeding relationship between two organisms. (A food chain illustrates how organisms within an environment interact with each other in terms of consumer/producer or predator/prey.)*

3. Explain to students that in today's lesson they will use their knowledge of food chains to create a food web. Ask students: Have you ever heard of food webs?
Answer: Some students might have in previous classes, but for some students the term might be new.

If students are having difficulties or are unfamiliar with food webs, have them focus on the word 'web.' Ask students: What is a web?
Answer: A interconnection of lines.

Ask a student to go to the board and draw a web.

Ask students: Where have you seen webs?
Answer: Examples that might help the students can be taken from the world of nature (such as a spider's web), or even from the world of technology (such as the WWW). When using the spider's web example, draw out the web and point out the chains and multiple connections within it. When using the World Wide Web example, have students explain why they think this structure is considered a web.

4. Return to the term food web and ask the students: Knowing what we do about webs, what do you think a food web is composed of?
Answer: food chains

5. Remind students about their investigation of sea lampreys in the Great Lakes. Explain that in today's lesson they will explore how organisms in the Great Lakes were connected through their food source/s **before the sea lampreys entered the environment**.

- Ask students what environment they read about last night in their Reader. *The Great Lakes*

- Tell students that their knowledge of the lake environment will help them create the Great Lakes food web.

Important: This food web lesson is based on the idea that the sea lamprey is not present in the Great Lakes environment. While the introduction of and presence of sea lampreys is vital to the overall unit, it will not be addressed until Lesson 10. This lesson is meant to help students describe and investigate the state of 'equilibrium' that existed before the sea lampreys entered the Great Lakes. However, we do not use the term 'equilibrium' due to its complexity. Instead we select certain components of the term to address the nature of the Great Lakes food web. The ability of students to make hypotheses and predictions about possible consequences of sea lamprey invasion (before the presentation of real data) is vital to the progression of student thinking and reasoning.

6. Explain to students that in today's lesson we will be looking at the types of organisms that live in the Great Lakes as well as some organisms who live on the land around the Great Lakes. We will look at how these organisms are connected to each other.
Tell the students that they will each be given a card that contains a picture and brief description of an organism. They will each represent a population of that organism."

Common Student Conception: Students might think that since there are only 17 different cards there are only 17 different organisms found in the Great Lakes. There are many more organisms that depend on the great lakes for their survival. These 17 organisms are a representative sample of that group. Also remind the students that each card stands for a population of that organism. Each person is not an individual organism, but rather a population.

Teacher Background Information:

For the purpose of this activity, we did not separate the two different kinds of plankton. There are two kinds of plankton: zooplankton, which are microscopic animals and phytoplankton, which are microscopic plants. To simplify the lesson, we will refer to both groups collectively as plankton. Students will be told only that they are microscopic organisms.

7. Distribute a card to each student. Because there are a limited number of cards, more than one student will represent the same organism. Explain to the students that they each represent a different population. Ask the students to read the information on their cards and think about who eats them and whom they eat.

8. Have the students get up and form a circle around the room facing each other. There will be some organisms who do not live in the water, but live on land. These organisms should form a group to one side of the larger circle. We will see later that they form a separate (terrestrial) food web, but they are connected to the aquatic web by what they eat.

Teaching Strategy: It will be helpful to arrange your classroom to accommodate students in their construction of the Great Lakes food web with balls of yarn. Moving desks out of the way of the circle is advised.

Conducting the lesson (25 minutes):

9. Ask the students: Does anyone have a card that shows that they do not eat another organism?

   Answer: The three producers – plankton, algae and aquatic plants.

   Ask the students: Why do you think these three organisms do not eat anything?
   Answer: They are the producers. They make their own food by converting sunlight and soil nutrients into food.

   Ask the students: Where should we start our food web?
   Answer: With any of the producers.

10. **Starting a Food Chain:**

Teacher Note: We are starting with plankton, but you may begin with any of the producers. If you are familiar with this activity feel free to jump down to the Relationship Key to see the specifics of this food web.

Give one of the colors of yarn to a student with a plankton card. Have them hold the end of the yarn. And ask the class who eats plankton?
There are a number of organisms that eat plankton (insect larvae, lake herring, aquatic clams and chubbs.

Have the student toss or give the yarn to a person holding an insect larvae card. Make sure that the student holding the plankton card continues to hold the end of the string. Ask the class what eats insect larvae?
Answer: Aquatic insects, lake herring, chubbs.

Have the insect larvae student hold on to the yarn and pass the rest of it to the lake herring student. Ask the class what eats lake herring?

Answer: yellow perch, lake trout

Have the lake herring student hold on to the yarn and pass the rest of it to the yellow perch student. Ask the class what eat yellow perch?

Answer: Walleye, Great Blue Heron, Turtle, lake white fish

Have the yellow perch student hold on to the yarn and pass the rest of it to the lake whitefish student. Cut the ball of yarn after the whitefish student making sure that the whitefish student holds the cut end of the yarn.

Explain to the students that they just completed a food chain. Ask the student to identify who is the producer; consumer; predator; prey; herbivore and carnivore.

Ask the students: What have we created? *A food chain*. What do we need to do to create a food web? *Answer: Add more food chains*.

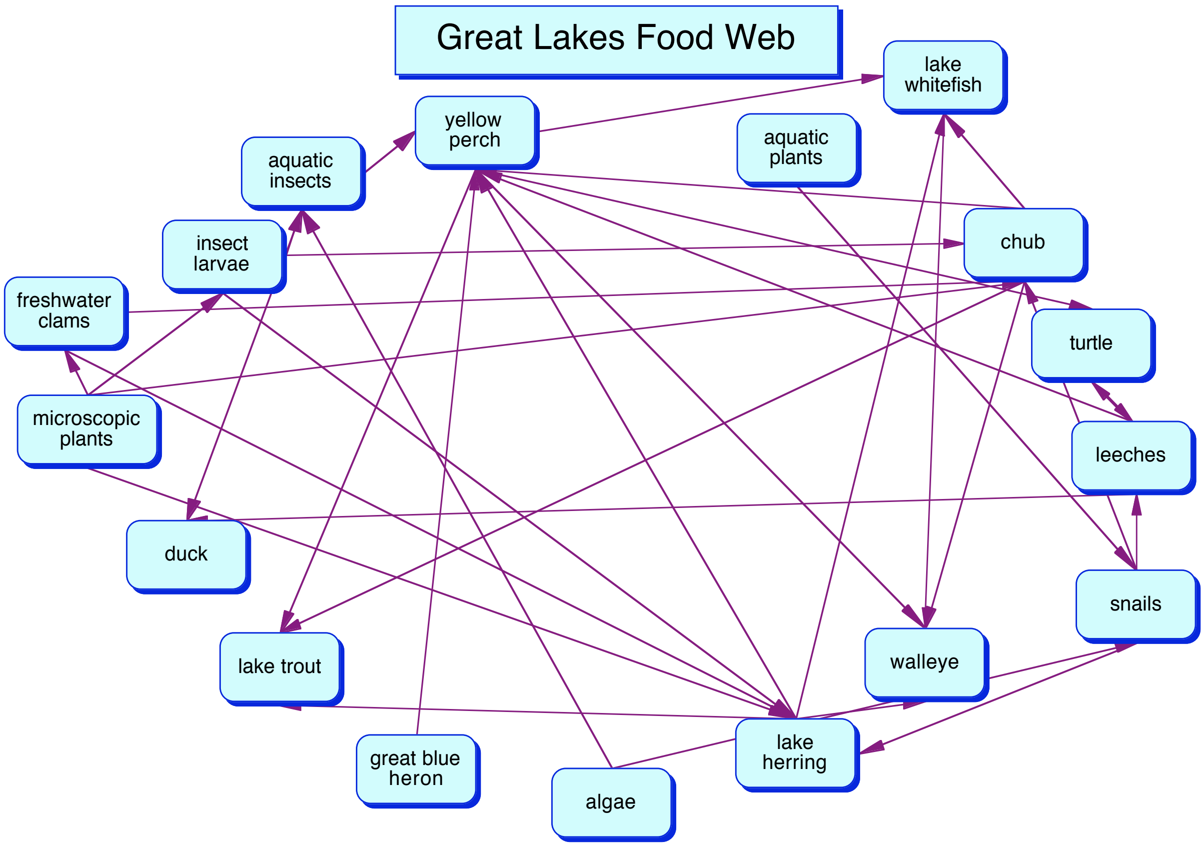
Using a different color yarn start with a different producer (algae or aquatic plants). And make a new food chain. Continue making new food chains until all students are holding at least one string. There will be more than five different chains and therefore you will need to reuse colors. Also there will be more than one student representing the same organism, therefore you may have to re-sequence a few of the food chains to accommodate every student. Be sure that the yarn gets passed to the organisms that are terrestrial (fox, wolf, etc).

Use the Relationship Key below and the food web diagram to help you in building food chains.

Relationship Key:
Producers: plankton, algae, aquatic plants

Aquatic insects eat insect larvae and algae
Insect larvae eat plankton
Yellow perch (fish) eat leeches, lake herring and chub fish
Walleye (fish) eats yellow perch, lake herring, lake trout, lake whitefish
Great blue heron (bird) eats yellow perch
Turtle eat leeches and yellow perch
Lake herring (fish) eat insect larvae, plankton, clams and snails
Lake trout (fish) eat lake herring and chub
Lake whitefish eat yellow perch, lake herring and chub
Tiny aquatic snails eat aquatic plants and algae
Tiny aquatic clams eat plankton
Leeches eat turtles and snails

Chubb (fish) eat insect larvae, plankton, clams, snails
Ducks eat leaches and aquatic plants



Important: Besides constructing food chains and food webs, we also want students to become familiar with the organisms that exist in the Great Lakes. This knowledge will facilitate student predictions about the consequences of food source changes when the sea lamprey data is introduced.

11. At this point, you and your students should be interconnected to each other through all the different colors of string. Explain to the students that we have just created a food web. And that a food web is made up of many food chains. Ask the students: Who is a part of more than one food chain? (Have students raise their hands).

Ask the students: Why are there some organisms involved in more than one food chain? *Answer: Because they eat more than one thing. Point out to the student that you eat more than one thing, so you must belong to more than one food chain.*

Ask the students: If there were no overlap between the food chains, would we have a food web? *Answer: no*

Ask your students if any of them are connected to the organisms outside of the large circle (the terrestrial organisms)? *Answer: Some should be connected to the fox, wolf, etc. This shows that the two food webs (aquatic and terrestrial) are also interconnected by organisms that feed in both places.*

Explain to the students that these connections are what hold the food webs together. What do you think will happen if we removed an organism from this food web? Do you think removing one organism (remember we are dealing in populations) will have a small or large affect on the food web? Have the students predict what they think will happen.

Tell the students that a fish disease came and wiped out half of the yellow perch population. Ask one of the students who is the yellow perch to drop their string and move away from the circle.

Ask the students: What happen to our food web? *Answer: Students should observe that some of them are lax.*

Tell the students: If you are holding a string that is lax, then drop it and move away from the circle. Ask the students: Why are these other organisms disappearing in our food web? Answer: If their food source disappears then they will starve and eventually the population will die off.

Tell the students: The fish disease has gotten worse and the entire population of yellow perch is gone. Anyone yellow perch holding a string drop it and move away from the circle. And now, anyone holding a lax string should do the same.

Common Student Conceptions: Students might think that as soon as the food source is gone then that organism is gone. It is only gone in respect to that food chain. Animals eat more than one thing; therefore if one of their food sources is gone then they will eat more of the other food sources for their survival.

At this time, all students can drop their string and go back to their seats.

Concluding the lesson (5 minutes):

12. Ask the students: What happened to the food web when we removed the yellow perch? *Answer: The connections the yellow perch had with other organisms where affected.*

Explain to the students that the “interconnectedness” is what makes a food web strong and that breaking one of those connections has an affect on the rest of the plants and animals that live within the same environment. The second half of this lesson looks at what effects changes to a food web have on an ecosystem.

Stop & Think: By the end of this session, students should understand that food webs consist of connecting food chains. They should understand that the Great Lakes are a freshwater aquatic environment with many organisms in it, all connected by an interconnecting food web. In addition, they should understand that this aquatic food web is connected to a terrestrial food web. Finally, students should be able to identify the types of relationships that exist between organisms in this food web: producer/consumer or predator/prey.

Day Two

Introducing the lesson (10 minutes):

4. Remind students that they had created the Great Lakes food web in yesterday's activity. Ask students: What did we mean by the term food web? What did our food web illustrate? *Answer: A food web is composed of many interconnected food chains.*
5. Have students recall what happened to the food web when they took out a population of an organism. Students should say that the food web fell apart and that different food chains were affected by this organism's absence.
6. The important question to ask students is: Before the removal of this one organism, what did our Great Lakes food web illustrates? If students have difficulty answering this question, ask them what makes a food web different from a food chain. Students should be able to recognize that a food web shows the interconnectedness of an organism to other organisms (whether directly or indirectly) within an environment.
7. Explain to students that in today's lesson they will use their knowledge of food chains and food webs to understand and to predict what happens to the organisms within an environment when a change (either a removal or an addition of an organism) in their food source occurs.

Conducting the Lesson (25 minutes):

8. Have the following food chain up on the board prior to class.

   Algae ---- aquatic snails ---- chubbs ---- lake trout

   Ask the students: Predict what would happen to each of the organisms if the snails were removed from this food chain? (Remind them we are talking in terms of populations of organisms and not individuals.)

   Answer: Algae population in this food chain would increase because nothing would be eating it and the chubbs population would decrease do to one of their food sources being gone. That would cause an indirect decrease of lake trout.

9. Put the overhead of the Great Lakes food web up on the overhead projector. And ask the students: If the snails are removed are there any other organism it would be affected? *Answer: There are many directions that students can take with this question. For example, they could talk about the affects within another food chain that involves a snail. (aquatic plants --- snails ---- turtles ---- leaches ---- duck) or they could talk about a more indirect route. For example, we know that the algae population is increase because the snails are not consuming the algae. More algae*

mean more food for the aquatic insects, which means an increase in the aquatic insect population. Indirectly there will be more food for the yellow perch, thus a possible increase in their population.

Encourage students to think past the direct relationships and more towards the indirect relationships.

10. Discuss with the students that the predator/prey and producer/consumer relationships are not only what connect the organisms to each other, but also "balance" the food web. If one organism or a whole population is removed from the web, then it upsets the balance. This not only causes the organisms that are directly connected to the removed organism to be affected, but also affects the organisms that are indirectly connected to the removed organism.
11. Students will need their Student Sheets for Lesson 8.
12. Using the food web overhead page or the food web diagram on their Student Worksheets, have students imagine what would happen if the species they represented was removed from the food web. Have them answer *questions 1 and 2 on their Student Worksheet*. (Answers can be found on the Teacher Answer sheet following this lesson.)
13. Have some students describe the outcomes of their scenario. Ask the class why they think certain organisms were affected earlier or later rather than all at the same time. Students should be able to recognize direct and indirect connections within a food web and thus explain why certain organisms are affected either immediately or at a later stage.
14. Have students answer *question 3 on the Student Worksheet*: What will happen to the food web if all of the chubbs and herring were taken out of a food web by an invasive species? What will happen to the rest of the organisms in the Great Lakes?
15. Have some students describe the outcomes of this scenario. Ask the class to hypothesize about the effects of the fishes' death on the Great Lakes food web. Since many organisms are connected to fishes, students should be able to predict the how severe the effects would be. While some organisms will increase in number as a result of the disappearance of forage fishes that eat them, other organisms will decrease in number as a result of the disappearance of forage fishes that they normally eat.
16. We've been talking about removing different organisms from the environment, what if something was added instead of removed? If a new organism invaded the environment and held the same position in the food web as a native organism, have students consider all the possibilities of what might happen. *Answer: There would be a competition between the invasive (added) species and the native species.*
17. Ask the students: Do you think that the changes that occur in the Great Lakes food web would affect the organisms that live on the land? *Answer: Yes, because the terrestrial food web is connected to the aquatic food web. Some of the birds and other animals feed on the aquatic plants and fish also live on land and are prey for organisms that live there.*

Stop & Think: By the end of this discussion, students should understand that organisms can be in a competitive relationship in a food web. Two organisms can compete for the same food source.

Concluding the lesson (5 minutes):

18. Relate this activity to the KWL. Explain to students that today we learned how an organism survives through its interconnections with other organisms in the environment. Through the construction of food webs, we are able: a) to see how an organism eats other organisms (which eat other organisms) to survive and b) to predict and hypothesize how an organism is affected when the food web is disrupted.

Homework:

Have students complete their Students Worksheets.

Connection To Next Lesson:

In the next lesson, students will be looking at how individuals and populations compete for food within the same environment. They will be looking at how this competition affects population survival.