CHARACTERIZING TEACHERS' SUPPORT OF CONSTRUCTING SCIENTIFIC EXPLANATIONS FROM A DISCOURSE PERSPECTIVE

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Paper presented at the American Educational Research Association, April 2006
San Francisco, CA

Abstract

Participating in the practice of constructing scientific explanations means, in part, understanding the norms for this practice. I studied two teachers' support of constructing scientific explanations and asked *what is the nature of teachers' support as they engage students in constructing scientific explanations?* Specifically, I was interested in what aspects of the practice of scientific explanations did the teachers attend to, in what ways they supported students in this practice, and how explicit they were about communicating the norms for participating in this practice. I take the perspective that inquiry practices such as constructing scientific explanations are part of the Discourse of science and as such include cognitive, social, and linguistic dimensions. I analyzed the teachers' enactments from this Discourse perspective and found that their support in each of these dimensions could, at times, be very tacit and subtle. This has implications for how we make the norms for complex inquiry practices explicit and, therefore, more accessible to all students.

Introduction

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 then 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 *Standards* 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 (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 (Lemke, 1990). To complicate matters further, students are often expected to engage in complex scientific practices without explicit instruction on how to do so. 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 of school and their out-of-school cultures, we need to make the norms for participation in school practices explicit to students (Delpit, 1988). Teachers play a key role in supporting students in their inquiry endeavors. The question, however, remains of *what does it mean to be explicit about the norms of an inquiry practice?*

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). Furthermore, research on students' participation in inquiry tends to focus on the artifacts of students' inquiry and students' cognitive processes during inquiry practices (McNeill et al, 2006) and not on the instruction around students' participation in inquiry. While this research is invaluable in understanding how students participate in inquiry practices, 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).

This study attempts to systematically describe how teachers operationalize the complex nature of scientific practices given curriculum materials that attempted to make the practice of scientific explanations explicit to students. I use a framework that describes inquiry as a Discourse 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 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[1] (Gee, 1996). As I will expand on in the next section, inquiry as a Discourse involves students in

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[1] 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.

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. These cognitive, social, and linguistic practices work together as a system to give students more authentic experiences as they engage with inquiry science materials.

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. I argue that it is students' unfamiliarity with these rules that 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 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—given an inquiry curriculum that attempts to make norms explicit for students—what sense teachers make of these norms and how they attempt to support them.

I argue that this description of teachers' enactments of inquiry practices 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.

Supporting students' construction of scientific explanations

This study was part of the IQWST project (Investigating and Questioning our World through Science and Technology), an effort to design standards-based science inquiry curricula for middle schools. The IQWST curriculum materials focused on attempting to make the practice of constructing scientific explanations visible to students (McNeill, Lizotte, Krajcik, & Marx, 2006). In this paper, I examine one inquiry practice, constructing scientific explanations, and how this practice was supported by two teachers enacting the same IQWST unit. Given that the curriculum included prompts for teachers to support students in the practice of constructing scientific explanations, I ask the question: *what is the nature of teachers' support as they engage students in constructing scientific explanations?* Specifically, I was interested in what aspects of the practice of scientific explanations did the teachers attend to, in what ways they supported students in this practice, and how explicit they were about communicating the norms for participating in inquiry practices.

The practice of constructing explanations is a central sensemaking practice of scientists (Driver, Newton, Osborne, 2000). It has the potential to engage students in the discourse practices of scientists, the processes of science, and the thinking forms of science (Kuhn, 1993). Finally, engaging in constructing scientific explanations and argumentation around those explanations can lead to more dynamic views of science (Bell & Linn, 2000) and away from the view of science as a "rhetoric of conclusions" (Schwab, 1966). As I said earlier, giving students opportunities to participate in the dynamic nature of scientific knowledge building may be one way to make scientific practices more visible and accessible to all students (Lemke, 1990).

In the IQWST materials, a scientific explanation was defined as containing three components: a claim, evidence, and reasoning (McNeill, et. al, 2006). A claim is a testable statement or conclusion that answers a scientific question. Evidence is scientific data that supports a claim. In the IQWST materials, evidence needs to be both *appropriate* and *sufficient* to count as evidence that supports a claim. Finally, reasoning is a justification that shows why the data count as evidence to support the claim. Reasoning also includes an appropriate scientific concept that links the evidence to the claim. In this study, I will use IQWST's model of explanations to explore what elements of the practice the teachers supported. I will also discuss, based on my characterization of the teachers' support of students in this practice, what this means for challenges students might face as they engage in this practice in an inquiry context and, consequently, what this means for reaching the ideal of "excellence and equity" for *all* students in science. In the next section, I describe the theoretical framework on which I base my characterization of teachers' support of the practice of constructing scientific explanations.

Theoretical framework: A multidimensional perspective of inquiry practices

Inquiry practices such as constructing scientific explanations 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 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.

As I mentioned in the previous section, I take the perspective that inquiry science represents practices in the Discourse of science, and that these practices present challenges to students on multiple levels. Gee (1996) 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 norms of reasoning, interacting, and using language that are shared by scientists. This is related to Aikenhead's (1996) argument 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.

We can apply this framework to the practice of constructing scientific explanations. Aspects of this practice in all three dimensions are summarized in Table 1. 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 IQWST, constructing a scientific explanation involves making a claim, having evidence to back up that claim, and reasoning that links the claim to the evidence (McNeill, et al 2006). 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.

Dimension	Possible Norm
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

Table 1. Applying the Discourse framework to the practice of constructing scientific explanations. Summary of possible cognitive, social, and linguistic norms for this practice.

Methods

In this study I describe two case studies of teachers' enactments of the same inquiry-based science curriculum in the spring of 2003. Both teachers, Denise and Sherry, had previous experience enacting inquiry-based science curricula developed by the Center for Learning Technologies in Urban Schools (LeTUS), a collaboration between Northwestern University, Chicago Public Schools, University of Michigan, and Detroit Public Schools (Blumenfeld, P., Fishman, B. J., Krajcik, J., Marx, R. W., & Soloway, E., 2000). The current study took place within the context of the IQWST project, a collaboration between Northwestern University, University of Michigan, and Project 2061 to design standards-based inquiry curricula for middle schools (Reiser, Krajcik, Moje, & Marx, 2003). Members of the IQWST team identified Denise and Sherry as teachers who had experience using inquiry-based approaches to teaching science but were neither exceptional inquiry teachers nor "traditional" didactic teachers. I therefore use them in this study as cases of "normative" inquiry teaching, in which the teachers may be defining and adapting inquiry to their instructional contexts. I was interested in 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. 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 curriculum for students who may not be familiar with inquiry approaches to teaching and learning.

Denise's class consisted of 29 eighth graders. From interviews with Denise, I learned that the class was over 90% second-language learners, and that language in science was one of her main concerns. The students in this class were identified, through their standardized test scores in mathematics, to be the "gifted" class, although by Denise's own admission, this meant reading out of a textbook and not having much experience with hands-on laboratory work like using microscopes, taking measurements, or engaging with data.

Sherry's class consisted of 27 eighth graders. The students in this class were also identified as being "gifted" through their scores on standardized tests. At the time of the pilot test, this class had been together as a class for more than one school year. Sherry did not take credit for building the community in the class and would often tell me how "lucky" she was that this class had such "great chemistry". Indeed, unlike many classrooms in which students only talk to the teacher during discussions, the students in Sherry's class talked to each other, asking each other questions and challenging each other.

Data collection

Denise and Sherry were part of the pilot test of an eight-week inquiry-based, middle-school curriculum focusing on ecosystems and natural selection. The curriculum, entitled *Struggle in Natural Environments: What Will Survive?* (Bruozas, et al, 2004) involved students in two major investigations, the first of which was the focus of this study. This investigation centered around the effects of an invasive species, the sea lamprey, 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. Students' goal for this investigation was to formulate a proposal to rid the Great Lakes of the sea lamprey, an invasive species, by learning about how the sea lamprey's biological structures enabled it to out-compete native organisms in the Great Lakes ecosystem.

Classroom observations were videotaped and field noted every day of the enactment of the curriculum. From this corpus of observations, five lessons were selected for deeper analysis based on the opportunities they afforded students to engage in part or all of the practice of constructing scientific explanations. In this unit, students were often asked to make predictions based on preliminary evidence or scientific principles. We considered these to be a variation on the practice of constructing scientific explanations. In the unit, students were asked to provide a claim (their prediction), evidence (from preliminary data), and reasoning based on scientific principles such as predator/prey relationships. Finally, semi-structured interviews were conducted with teachers and students three times during the enactment to triangulate data collected in the classroom.

Data analysis

Using the IQWST model of claim/evidence/reasoning, key lessons were transcribed and coded for instances of teachers' supporting part or all of the practice of constructing scientific explanations. 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 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. In the following sections, I discuss the norms teachers communicated within each dimension, how explicit they were in that communication, and implications of this analysis on students' learning how to engage in the practice of constructing scientific explanations.

Findings

In the beginning of the *Survive* curriculum, teachers were given a written primer on scientific explanations, why they are important to helping students construct scientific knowledge, and how to support students' construction of scientific explanations in the classroom. These are shown in Figure 1.

1. **Make the framework explicit**. You want to help students understand the three components of explanations. They should understand what these three components are as well as the definitions of the three components.
2. **Model the construction of explanations.** After introducing explanations, you want to model how to construct explanations through your own talking and writing. When it is appropriate, provide students with examples of explanations. Furthermore, identify for students where the claim, evidence, and reasoning were in your own example.
3. **Encourage students to use explanations in their responses.** During class discussions, if a student makes a claim ask them to provide an explanation for that claim. Encourage student to allows provide evidence and reasoning to support their claims.
4. **Have students critique explanations.** When students write explanations in class, you may want to have them trade their explanations with a neighbor and critique each other's explanations. Focus students' attention on discussing both the strengths and weaknesses of their partners' explanations and offering concrete suggestions for improvement. You may want to show students an overhead of a generic student's response and as a class critique the explanation. Or you may want to provide students with an example of a scientific explanation from a newspaper, magazine or website. Then you could have students critique the explanation in terms of the claim, evidence, and reasoning.

Figure 1: Guidelines provided to teachers for supporting students' construction of scientific explanations in IQWST units.

Although these guidelines serve as suggestions to teachers about how to incorporate support of scientific explanations into their discussions, they are by no means prescriptions for what teachers should do in their classes and, in fact, are open enough to allow for some variation. For example, what does it mean to "model" the construction of explanations and what might that look like in classrooms? One can imagine a teacher being very explicit in her modeling, closely mapping between the claim/evidence/reasoning framework and her own explanation. Or, a teacher could be very tacit and subtle with her modeling, leaving much of the work up to the students to infer the norms for constructing scientific explanations. In this section, I give some examples of how the inquiry as a Discourse perspective can characterize teachers' support of the claim/evidence/reasoning framework of scientific explanations and how this support can be very tacit and subtle at times. This has implications for inquiry being used as a tool for reaching the ideal of "excellence and equity" put forth by *The National Science Education Standards*.

Tacit and explicit support for providing evidence and reasoning for claims: two examples of using the linguistic dimension to enhance a cognitive task

In the IQWST model of constructing scientific explanations, reasoning is a justification that shows why the data count as evidence to support the claim and includes appropriate scientific concepts. Reasoning is typically the most challenging aspect of explanations for students to provide because often students make a general link between the claim and evidence but fail to provide a scientific concept that makes the evidence relevant to the claim (Bruozas, 2004). Because of this difficulty, it seems important for teachers to be explicit about when to provide reasoning and what form that reasoning should take. In this section, I give two examples of teachers' support for providing reasoning for claims. The first, from Sherry's class, is an example of subtle, tacit support that makes use of classroom norms for cueing students to next steps in the practice. The second example, from Denise's class, is an example of explicit support in which the teacher makes use of the linguistic dimension and modeling strategies to help students construct their explanations. I will then discuss the tradeoffs of each strategy and their implications for making this practice accessible to all students.

Sherry: tacit support for providing evidence and reasoning for claims

The following example is from a whole-class discussion in Sherry's class in which the class is trying to make predictions about what will happen in a food chain if the aquatic snail was taken out of the food web. This discussion is an example of how the inquiry as a Discourse perspective—specifically, looking at the linguistic dimension of the task—can highlight both the subtle cues that teachers are using and the norms they are communicating about the practice of constructing scientific explanations.

1 Sherry: Ok so the things that eat perch, what happens to those things?
2 Kevin: They go down.
3 Sherry: They go down.
4 Kevin: The population.
5 Sherry: **Why?**
6 Kevin: Because lack of food.
7 Sherry: Ok what about the things the perch eats? What's going to happen to that population Danielle?
8 Danielle: Things the perch eats?
9 Sherry: Mm hm
10 Danielle: Um, would they grow more?
11 Sherry: **Why?**
12 Danielle: Because the perch wouldn't be eating them?
13 Sherry: Ok. [turns on overhead] In this food chain [pauses to look at lesson plan]…today we're going to look at what happens when you take something or put something new in a food chain. In this food chain [shown on overhead]:

algae-aquatic snails-chub-lake trout

14 you have algae, aquatic snail…uh, chubs, and lake trout. If something happens to the aquatic snails and that population goes, what's going to happen to the algae?
15 Larry: They'll grow
16 Sherry: **Why?**
17 Larry: Because there's less things that will eat it.
18 Sherry: Ok so population grows…what's going to happen to the chub? Adrian?
19 Aiden: It will die
20 Sherry: **Why?**
21 Aiden: Without the aquatic snails it will die out unless it has another organism it can eat.

In this example, Sherry manages to engage students in the practice of providing reasoning for their claims. It is worth mentioning here that the students did not provide evidence, presumably because the evidence would have been simply restating what was shown in the food chain. For example the evidence for Larry's claim that the algae will grow would have been: *in the food chain, the aquatic snails eat the algae*. What we see Larry providing instead, is a "there's less things that will eat it", which is a reference to a more general scientific principle that if an organism's consumer dies out, that organisms' population will increase.

From a Discourse perspective, Sherry utilizes the linguistic dimension of this practice to accomplish the cognitive task of providing reasoning for a claim. Notice, that the prompt Sherry uses throughout this example is simply the question "why". In this case, the word "why" seems to be coding for an important part of the practice—that of providing reasoning for a claim. In this way, the word "why" becomes a discourse marker (Schiffrin, 2003; Chaudron & Richards, 1986; Tree, 1999), or a single word or strings of words that encode information or behavior. This information or behavior is taken by the speaker to be understood by the listener. For example, transition discourse markers such as "on the other hand", "to begin with", and "for the moment" can serve various functions such as organizing content, connecting topics, indicating topic continuation, and closing a topic (Chaudron & Richards, 1986). In Sherry's case, the discourse marker "why" accomplishes two things. The first is to signal 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 norm that claims (in this case 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 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 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 both information in a scientific dialogue, but it also shows how subtle the cues are for communicating the norms of participation in the practice constructing scientific explanations. 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).

Denise: Explicit support for providing evidence for claims

In the IQWST model of scientific explanations, evidence is scientific data that supports a claim. The data need to be both appropriate and sufficient to count as evidence that supports a claim (Bruozas, et al, 2004). This means that students need to have evidence that is relevant to the claim they are making and that they need to provide enough evidence to support a claim. Making a claim 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 claim must be specifically referenced so others can decide for themselves if they believe a particular claim.

The act of referencing data can be challenging, 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 make claims 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] [Denise 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 make claims about what factors affected peacocks' survival and chances for mating. Students were to synthesize information from several graphs and charts in order to make these claims and provide evidence for them. In the beginning of the example above, Eric has just finished sharing his claim when Denise asks him to reference the data he used in making that claim. When Eric says "the chart", Denise uses this opportunity to explicitly model her expectations for referencing data in support of scientific claims. 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 claim. Denise reinforces this in line 315 by putting names to the parts of Mike's response: "conclusion" (or claim) 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 making claims based on evidence, but communication of expectations necessarily involved being clear about the meaning of "conclusion" and "evidence" in this context.

Referencing evidence in support of scientific claims 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. Of course, *all* communicate involves language of some sort, but the important point here is the level of specificity of the language that Denise expects. It is not only the fact that one needs to have evidence, but that the evidence needs to be referenced to a certain level of specificity which Denise models. Students were to not only reference a chart, but a particular *line* in the chart. In this case, the language modeling focused students on the *process* of referencing evidence for a claim. She succeeds in eliciting a specific data reference from Mike after she explicitly models the practice. Indeed, Mike's specific data reference differs markedly from Eric's response of "the chart".

Notice, however, that 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. Perhaps because of Denise's concern about her students' language abilities, she focuses this discussion on the language of how to reference evidence in support of a claim instead of the substance behind that evidence. Kuhn (1993) writes that "forms of thinking", like arguments or explanations, are powerful tools for making scientific processes accessible to students. In this case, the Denise made the form—of providing a claim and evidence—visible to students, but did not delve deeper into the substance of that form—how to be discerning about the evidence that one chooses to back up a claim.

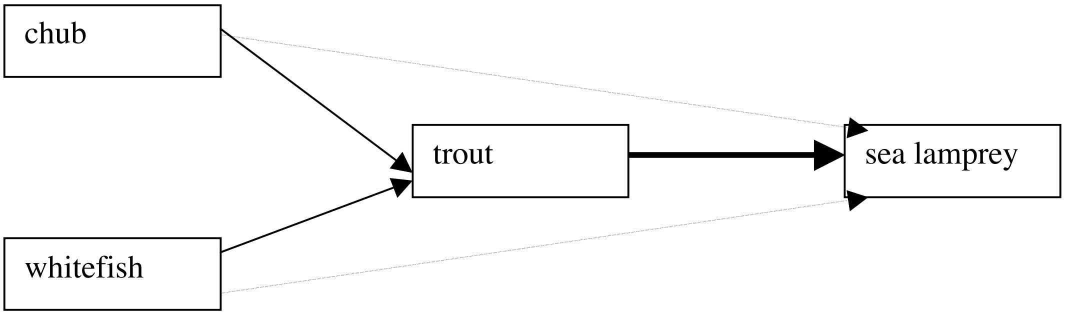
This is an example of how a teacher could set up an initial discussion of using data as evidence to back up a claim. In order to engage students in the full practice of constructing scientific explanations, Denise ideally would have set up a discussion of the merits of the evidence students presented and had them critique each others' arguments.

Using the social dimension to co-construct chains of reasoning with student

In the *Survive* unit, students were often asked to explain complex phenomena based on complicated data sets and representations. Often, complete explanations of phenomena entail a chain of events, parts of which may be distributed in different students' explanations. Instead of simply telling students what happened, however, the teachers asked a series of questions that, together with students' responses to those questions, culminated in a complete narrative.

In the next example, 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 based on evidence. 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.

Co-construction is an example of how teachers can use the social dimension of the task to accomplish complex cognitive work with students. 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 Denise's example above. Although Denise retains control of the conversation, she asks a series of guiding questions that eventually leads the students 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 Denise. 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.

Setting the stage for argumentation: using the social dimension to enhance the cognitive task of constructing scientific explanations

As I mentioned earlier, the practice of constructing scientific explanations is closely related to the practice of argumentation. An explanation is a position for how or why something occurs. Argumentation, or the public discourse of defending a position, is the motivation for constructing an explanation that is as robust as possible (McNeill & Kuhn, 2006). Indeed, in the scientific community, argumentation happens in the public discourse of journal reviews and publications (Longino, 1990) and is a major tool for achieving objectivity in the construction of new scientific knowledge. In the classroom, students need to be aware that they have to defend their positions *against* others. If students never need to defend their explanations to their peers, they have no reason for carefully constructing their explanations with robust evidence and reasoning. However, teachers rarely engage students in argumentation. Deanna Kuhn (1993) argues that

> Those who have examined children studying science in classrooms or other group settings note that the opportunities such settings typically afford for students to appreciate the evidence-based nature of science, in particular the coordination of models, theories, and explanations with data and the contemplation of alternative models are scant (p. 334)

I found this to be true in Denise and Sherry's enactments as well. However, although they did not take explanations to the next level, I did find examples in which the teachers were attempting to make the students aware of alternative viewpoints in the class. These examples point to the importance of the social dimension in engaging in the cognitive task of constructing scientific explanations.

In the following example, 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 an explanation 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 make a claim 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 the following 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. In this case, 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.

Although students may see their role in the discussion as simply sharing ideas, the scaffolding that Denise does in this discussion suggests that she expects students to consider 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 but are also 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.

This type of support is important in the IQWST explanation model because it allows the class to see that there are multiple claims being presented in the class. This type of support is also important for setting the class up for argumentation, or the public activity aimed at justifying or defending a position for an audience (McNeill & Kuhn, 2006 In order to engage in argumentation, one needs to be aware that there are alternative positions to argue for or against (Kuhn, 1993). A scientific explanation is a justification for a particular claim, but the motivation for constructing that explanation is, in the context of IQWST units, a public defense of a position. This assumes that there are other positions to defend one's explanation *against*. What Denise manages to do in the preceding example is to draw out the different positions around the issue of which variable is most important in the peacocks' mating and, in so doing, sets the class up for the practice of argumentation. Although Denise does not take the class to the next level, this is an example of how a teacher could use aspects of the social dimension to enhance the cognitive task of constructing scientific explanations.

Discussion

In this paper I explored what aspects of the practice of constructing scientific explanations teachers emphasized and how they did so, given an inquiry curriculum specifically designed to support this practice. I used the perspective of inquiry practices as consisting of cognitive, social, and linguistic dimensions to analyze the ways in which teachers engaged students in the practice of constructing scientific explanations. The Discourse perspective allowed me to see how the teachers supported different dimensions of inquiry, and that the three dimensions served as a heuristic for looking at how explicit the teachers were in communicating norms for constructing scientific explanations.

The teachers did emphasize important parts of the practice. As I showed in previous examples, we saw both teachers emphasizing the importance of backing up claims with reasoning and evidence. We saw Denise co-constructing explanations with students, thereby scaffolding the students into the complexity of the practice. Finally, we saw Denise setting the class up for argumentation by articulating different perspectives on the same scientific question.

The IQWST curriculum materials included guidelines on how to make the explanation framework explicit to students. These suggestions included *modeling* explanations, *defining* the framework, and encouraging students to *use explanations* in their responses. I began this study with the perspective that part of how teachers introduce students into the Discourse practice of constructing scientific explanations would be 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. What I found instead was a range of explicitness in Denise and Sherry's support of inquiry practices. Sherry's subtle use of the discourse marker "why" was successful in her classroom context for eliciting reasoning from the students but it relied heavily on previously established classroom norms. This would be problematic for students new to that context or new to the language of science. Denise's explicit support for how to provide evidence for claims was an example of how a teacher could make parts of the practice very visible, but it also highlighted the tension between procedure and substance. Given very limited classroom time and energy, heavily emphasizing one part of a practice like the procedure for providing evidence may come at the expense of delving into the substance of that evidence.

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. 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.

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.

Acknowledgements

The author wishes to thank Brian Reiser for helpful feedback on the research presented in this paper. This research was funded by a doctoral fellowship from the Center for Curriculum Materials in Science, funded by the National Science Foundation under Grant ESI-0227557, and by National Science Foundation grants ESI-0101780, ESI-0439352, and ESI-0439493 to the IQWST project. The opinions expressed herein are those of the author and not necessarily those of the NSF. For additional information about IQWST curricula and research see http://www.hi-ce.org/iqwst

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