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Understanding the composite practice that forms when classrooms take up the practice of scientific argumentation

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ABSTRACT

Understanding the composite practice that forms when classrooms take up the practice of scientific argumentation

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Traditional classroom practices communicate epistemic commitments and goals that might be contrary to those needed for meaningful participation in scientific inquiry practices. In this dissertation, I explore how traditional classroom practices influence students' participation in the practice of scientific argumentation. I address this through a two-pronged approach. First, given that students do not typically engage in collaborative knowledge-building through scientific argumentation, I used the best-practices put forth by relevant research to support teachers in facilitating this practice. Second, I worked with four classes as they enacted a unit designed to foster scientific argumentation. I observed the emergent class discussions and engaged in discourse analysis in which I related the interaction patterns found in non-argumentative class discussions to those that occurred in lessons designed to foster scientific argumentation. Examining the argumentative discussions reveals that each class transformed the practice in different ways. Comparing these interactions to those of the non-argumentative suggests that students used the goals and beliefs that guided their typical classroom practices to interpret the activity structures for and teacher's framings of the new practice of scientific argumentation. In this dissertation, I present a research methodology for understanding the relationship between typical classroom practices and student adaptations of new scientific practices; design strategies for supporting scientific argumentation; and a framework for

understanding how and why classroom communities adapt the practice of scientific argumentation.

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Chapter 1: Introduction

A recent movement in the science education community sees the discourse of argumentation as a key way for students to learn science (e.g. American Association for the Advancement of Science, 1990; Duschl & Osborne, 2002; Duschl, Schweingruber, & Shouse, 2007; National Research Council, 1996). The general line of reasoning in this literature is two-pronged. First, by engaging in argumentation students have an opportunity to develop understandings of the scientific ideas. That is, rather than memorizing the words of someone else, engaging in the discourse of scientific argumentation provides students with the opportunity to internalize the scientific concepts and make them their own (Vygotsky & Kozulin, 1986; Wertsch, 1979). Second, argumentation is, by its very nature, a dialogic activity in which individuals interact with one another. Through this discourse, the learning experience moves beyond the individual and becomes an opportunity for students to learn from one another, constructing knowledge together. Moreover, it is hoped that this discourse will provide a tool for knowledge construction; students learn not only that ideas can be questioned, but they also learn how to question ideas (e.g. Duschl, 2000; Newton, Driver, & Osborne, 1999; Sandoval & Reiser, 2004).

However, argumentation rarely happens in science classes. Newton, Driver and Osborne (1999) provide evidence of this in an observational study of classroom interactions. In this work they find that the instances of communal knowledge construction through argumentative discourse were "few and far between." Lemke (1990) also demonstrates this lacking in his research, in which he characterizes the majority of the classroom interactions as being teacher driven. Further evidence of the lack of argumentative discourse lies in the large number of studies designed to foster it. This work has uncovered obstacles to argumentative discourse in science classrooms such as students' lack of substantive engagement with one another's ideas (e.g. Brown & Campione, 1996; Hatano & Inagaki, 1991; Scardamalia & Bereiter, 1994) and struggles with constructing claims that align with the available evidence (Kuhn, 1989; Kuhn, Amsel, & O'Loughlin, 1988; Kuhn, Black, Keselman, & Kaplan, 2000; Zeidler, 1997).

In this dissertation, I am broadly interested in exploring ways to engage students in the complex practice of argumentative discourse. I investigate how and why students take up this practice in science classrooms. Before exploring this, we must clarify the goal: what is scientific argumentation? After defining the goal more carefully, I examine why it does not occur more often: why is argumentation hard for science students? I explore these two questions in this chapter in order to construct a more careful articulation of the research questions that motivate this dissertation.

1.1 What is scientific argumentation?

The science education literature discusses the practice of scientific argumentation as a vehicle for developing robust scientific explanations. Andriessen (2007). calls this form of argumentation "arguing to learn," which he defines as "a form of collaborative discussion in which both parties are working together to resolve an issue…" (p. 443). From this perspective, the work of resolving an "issue" or disagreement is the way in which individuals collaboratively construct explanations of a scientific phenomenon: individuals compare conflicting explanations with the supports for those explanations and work to identify or construct an explanation that best fits the available evidence and logic. As stated by Sandoval and Millwood (2005) "explanations are a central artifact of science, and their construction and evaluation entail core scientific practices of argumentation" (p. 24). Thus, research on the practices of both scientific argumentation and explanation in classrooms often examines the goals of argumentation and goals of explanation together (de Vries, Lund, & Michael, 2002; Herrenkohl & Guerra, 1998; Hogan & Corey, 2001; Sandoval & Reiser, 2004).

For example, Hogan, Nastassi and Pressley (1999) examine student reasoning as it is apparent in their explanatory and argumentative discourse, without differentiating or defining these modes of communication. In addition, Bielaczyc and Blake (2006) show students' use of argumentation when building explanations, while neither differentiating nor naming these two practices. Instead, building on Scardamalia and Bereiter (1994), these authors refer to the combination of these practices as "knowledge building." In both of these examples, the process of constructing an explanation occurs through the process of negotiating understandings as students attempt to persuade one another of their explanations.

This view of argumentation and explanation as complementary is implicit even in learning environment interventions that differentially emphasize these practices. For example, one approach to fostering student engagement in argumentation and explanation is to put student explanations in opposition such that they are in positions to persuade one another (e.g. Bell & Linn, 2000; Hatano & Inagaki, 1991; Osborne, Erduran, & Simon, 2004). These researchers and designers foreground argumentative discourse such that the instructional emphasis is on argumentation, and the scientific explanations are a result of this process. Another common approach is to support students in constructing explanations that can be defended with evidence (e.g. McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Reiser, 2004; Suthers, Toth, & Weiner, 1997; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). This second strategy uses guidance related to the structure of a scientific argument—claims defended with evidence—to support students' explanation construction. It is important to note that while I contrast the emphases of these two design approaches, they both focus on the broad goals of explanation and argumentation. Their differences lie in the aspects that they choose to emphasize and how it is made explicit through their interventions.

Given this overlap, I use a single term—scientific argumentation—to refer to the process of constructing explanations through argumentative discourse. I choose this term because my work focuses on the dialogic aspects of this complex practice. That is, in my analyses, I foreground how students interact with one another's ideas—how they argue—over a second (but important) goal of knowledge construction—or explanatory—processes.

While combining the practices of explanation and argumentation makes sense in terms of their related pedagogical goals and processes, it results in a complex practice with multiple instructional goals. Moreover, as some of the instructional goals may be more challenging for students than others, this complexity requires that we tease apart the goals of argumentation in order to better understand and support students in engaging in all aspects of it. For example, students may find the argumentative goal of defending an explanation against critique more challenging then the explanatory goal of communicating a causal account of an event. In addition, the different goals may require different types of support. Should supports for using evidence to make sense of a phenomenon differ from those for using evidence to argue for claims about that phenomenon?

Given the complexity of this combined practice, I begin by identifying the underlying instructional goals of scientific argumentation (first presented in Berland & Reiser, in press).

These goals create a language for both understanding the ways in which students take up this complex practice and for describing and refining the contexts that designers and teachers create in order to support student engagement in scientific argumentation. I therefore use this framework throughout my dissertation to describe the instructional supports used and to explain student engagement in the practice. After defining these goals, I examine how argumentation accomplishes these goals by exploring both the product and process of scientific argumentation.

1.1.1 Three instructional goals of scientific argumentation

Drawing on relevant design research, analyses and theory, Berland and Reiser (in press) identified three distinct goals that emerge from attempts to support and study student engagement in scientific argumentation: 1) using evidence and general science concepts to *make sense of the specific phenomena being studied;* 2) *articulating these understandings;* and 3) *persuading others of these explanations* by using the ideas of science to explicitly connect the evidence to the knowledge claims. Each of these goals is a crucial piece of knowledge building via the social process of evaluating and defending claims, as such they identify instructional goals—they are reasons an educator would facilitate argumentative discourse. Thus, we proposed the goals of *sensemaking, articulating* and *persuading* as a framework for understanding student participation in the practice of scientific argumentation. In the following section I define each of these goals and highlight their instructional value.

The first goal of argumentation is for students to *make sense* of the phenomena they investigate. Duschl (2000) and others emphasize that the nature of this sensemaking must be influenced by the particular discipline with which the students are engaged. That is, since evidence is at the core of scientific sensemaking, the sensemaking in which students engage must rest on the alignment between their evidence and claims (Driver, Newton, & Osborne, 2000; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). For example, sensemaking occurs when students interpret population graphs in order to construct a causal account for why a population changed. This process of actively engaging in sensemaking is a key component of students developing a deep level of content understanding, rather than a superficial memorization of facts (Chi, Leeuw, Chiu, & Lavancher, 1994; Coleman, 1998).

"For scientific ideas, their explicitness is what sets them apart, because without explicit formulations of facts and methods, there would be no science" (Ford, 2008, p. 418). Thus, the second goal of scientific argumentation is to *articulate* one's understandings about what or why an event occurred. As stated by Sawyer (2007): "Articulating and learning go hand in hand, in a mutually reinforcing feedback loop" (p. 12). Other science educators agree with this focus on communication as part of learning: The basic tenet of this perspective is that communication provides students with opportunities to identify the strengths and weaknesses of their understanding (Bell & Linn, 2000; Davis, 2003; de Vries et al., 2002; Scardamalia & Bereiter, 1994). Using the previous population example, articulation occurs as students use the language of science to tell their classmates and teachers the causal account they constructed to explain the population fluctuations. Thus, this second goal of articulating one's understandings through argumentative discourse is one step in the process of developing shared understandings of the phenomenon under study.

The third goal of argumentation, *persuasion,* emphasizes the complexity of knowledge building by describing it as social process of considering and reconciling competing ideas from multiple individuals in order to construct the most robust explanation of the phenomenon under study. This is both a key aspect of how scientists engage in sensemaking (e.g. T. Kuhn, 1962; Latour, 1980; Toulmin, 1972) and an instructional strategy for making knowledge construction a meaningful practice for students in a classroom (e.g. Lehrer & Schauble, 2006; Scardamalia & Bereiter, 1994; Warren & Rosebery, 1996). Thus, if we hope to engage students in scientific knowledge-building practices, they must participate in the collaborative, persuasive discourse of consensus building. That is, students' articulations of their sensemaking should become proposals to the community: the community in turn can consider differing proposals in order to reach consensus regarding how to best explain the phenomenon under study. In the population fluctuation example, students engage in the goal of persuasion when they identify evidence that supports each step in their causal account and use these justifications in scientific discourse with peers to compare and reconcile different plausible accounts.

When attention is paid to this goal of persuasion, students move beyond articulating their understandings, by working to convince their community of the scientific accuracy of their explanations. This persuasive discourse goes beyond articulating explanations by engaging students with the ideas of others, receiving critiques, and revising their ideas (Driver et al., 2000; Duschl, 1990, 2000). Emphasis on this goal has been seen to foster student engagement with the learning process and therefore engagement with the content under study. For example, D. Kuhn and Udell (2003) found that engaging in argumentative discourse strengthened the quality of inner-city eighth-grade students' articulation of their beliefs.

As this description makes apparent, the goals of sensemaking, articulating and persuading depend upon one another. However, they are not equivalent: one can imagine students articulating an understandable and plausible explanation with different degrees of success in the third goal of persuasion. Indeed, much of traditional school encourages students to articulate explanations without the expectation that it will be challenged or judged against other explanations (Driver et al., 2000; Lemke, 1990). Defending an understanding through persuasion changes the goal of the articulation in that the explanations are now potentially contentious. In other words, the goal of persuasion creates a "knowledge problematic" view of science such that individuals are acting as though they expect others to "draw different conclusions from the same perceptual experiences because they hold different theories that affect their interpretation of evidence" (Carey & Smith, 1993, p. 249). As a result, the goal of persuasion requires that students articulate why their classmates should believe the explanation, given the evidence. Thus, it is the goal of persuasion that shifts the classroom interactions around the practice of scientific argumentation from "doing school" to "doing science" (Jimenez-Aleixandre et al., 2000). That is, the goal of persuasion highlights the communal aspects of this practice and, as such, it takes seriously the view that individuals learn science through participation in scientific practices.

To be clear, sensemaking, articulating and persuading are not steps in a process. Instead the relationship between these goals is a fluid one: not only do individuals iterate between these goals while participating in arguments, but the goals also frequently co-occur. For example, unless an individual is working alone, the process of sensemaking requires that students articulate their developing understandings. In addition, it is clear that persuasion is an extension of students' articulations of their understandings – one cannot persuade without articulation. Finally, in order to determine if one is persuaded by an argument, or revise an understanding in light of competing evidence, one must make sense of the posited understandings and supportive evidence.

In this dissertation, I am interested in understanding whether and how students engage in the complex practice of scientific argumentation. These three goals provide a way to unpack their participation in argumentation—it provides a lens for understanding the successes and challenges that students face which, in turn, can inform the design of supports for fostering scientific argumentation. For example, in analyses presented in Chapters 4 and 5, I use these goals to differentiate between classes in which the students are eager to persuade others of their understandings but pay less attention to the sensemaking goal, and those in which students are more likely to carefully construct and articulate explanations but fail to communicate them in a persuasive way. Furthermore, each goal of this practice may require a different type of support. For example, using evidence when making sense of phenomena may be a key conceptual challenge that requires explicit teacher guidance, while engaging in the persuasive discourse of argumentation may involve shifts in how students and teachers interact.

Thus far, I have presented a theoretical analysis of the instructional goals underlying argumentation, but I have not yet described how this practice plays out. How do students interact in a discussion that addresses each of these goals? Methodologically, how can researchers determine when these goals are being met through classroom discourse? In the following section I describe both the product of argumentative discourse and the characteristics of an argumentative discussion.

1.1.2 How does scientific argumentation address these goals?

In order to understand how the practice of scientific argumentation can fulfill the goals of articulating, sensemaking and persuading I examine both the product of an argument and the process of constructing that product. Characterizing the product both creates a baseline understanding of what an argument should achieve—creates a way to assess the outcome of argumentative discourse—and identifies some of the components of argumentative discourse (i.e., if a component is necessary in the final product then it will presumably be discussed). Similarly, examining the process provides expectations regarding how an argument could proceed. Together these two components—the product and the discourse processes—are tools for understanding student successes and challenges with the three goals of scientific argumentation.

Following trends in the field of science education, as reviewed by Sampson and Clark (in press), I simplify Toulmin's model of an argument (1958) in order to identify the basic components of an argumentative product. In its final form, an argument consists loosely of a claim and the defense of or supports for that claim. These two pieces can be communicated through the course of an argumentative dialogue (discussed at more length below) or as the product of an argumentative discussion. For example, at the conclusion of a whole class discussion in which students used graphs of population sizes in order to identify the food of an unknown invasive species, one student wrote the following argument:

> I believe that the invasive species eats grass, because the rabbits were gone and the foxes was (sic) low. So it [the grass] is the only thing the invasive species could have been eating, because it is really high. (Bobbie, Ms. B, 2006)

In this short argument Bobbie has provided a claim (the invasive species eats grass) and defended it with both patterns that emerged from the empirical evidence (the rabbits were gone and the foxes were low but the grass population remained high) and a warrant (the only thing left for the invader to eat was grass).

Toulmin's model goes beyond the characterization of a solitary argument in order to identify components of counter arguments (arguments designed to challenge the focus argument) and rebuttals (statements that refute or preempt counter arguments). These aspects of Toulmin's model indicate that scientific argumentation is a social practice. That is, the inclusion of these components introduces the expectation that the construction of an argument includes attention to the opinions and ideas of others. However, while these components suggest this, this model of an argument remains focused on the final form or the product of the argument, and these components do not account for the argumentative process that results in this attention to the ideas of others. I look to other authors to understand the argumentative process.

As opposed to the argumentative product, there is little work that explicitly defines the characteristics of an argumentative discussion—the argumentative process. In fact, philosophers have identified multiple forms of arguments. Drawing from work such as Aristotle (1955) and Locke (1961 [1690]), Walton (1998) has identified six possible argumentative dialogues, each of which is "a goal-directed conventional framework in which two [or more] speech partners reason together in an orderly way….Each type of dialogue has distinctive goals as well as methods that are used by the participants to achieve these goals together" (Walton, 1998, p. 3). Work such as this suggests that argumentative discussions vary broadly based on the participants' goals and their patterns of interaction. Table 1.1 both summarizes Walton's dialogue types (as he describes them) and identifies the instructional goals emphasized by each dialogue type.

Table 1.1: Aligning Walton's (1998) argumentative dialogue types with the three instructional goals of scientific argumentation

Dialogue type	End result	Methods for achieving result	Instructional goals emphasized
Critical	Individuals are persuaded of a single claim	Criticizing counter arguments	Articulation, Persuasion
Inquiry	Claims are proven to be true or false	Collaborating to draw conclusions from premises/data	Articulation, Sensemaking
Negotiation	A "good deal" is reached	Bargaining and compromising	Articulation, Persuasion
Information-seeking	An individual gains information	Asking questions and collecting information	Articulation, Sensemaking
Deliberation	A practical problem is solved	Debating possible courses of outcomes by predicting their outcome	Articulation, Sensemaking
Eristic	Opponents are defeated	Quarreling through aggressive tactics (including insults, emotional attacks etc.)	Articulation, Persuasion

As seen in Table 1.1, each of these dialogue types has a different end result. For example, the critical dialogue is used to persuade people, while the inquiry dialogue is a way to construct a single claim that is irrefutably supported by evidence (Walton, 1998). Table 1.1 also communicates my proposal for aligning the Walton's dialogue types with the three instructional goals of scientific argumentation. As shown, I propose that each of these dialogue types differentially addresses the instructional goals of scientific argumentation. For example, the first—critical dialogue—requires that individuals criticize counter arguments, thereby highlighting persuasion without necessarily demanding that participants reconcile their differences in order to make sense of the phenomenon under study. Thus, I aligned it with the goal of persuasion. In contrast, the inquiry dialogue appears to emphasize sensemaking over persuasion because it focuses individuals working together to interpret the data (or premises). As such, this dialogue type leaves room for individuals to learn from one another rather than placing them in opposition (as the critical dialogue does).

Notice that none of Walton's dialogue types appear to emphasize both persuasion and sensemaking. This demonstrates the complexity of scientific argumentation: it is difficult to achieve the three overarching goals of the practice within the confines of the norms that govern typical discussions. Walton addresses this by stating that scientific argumentation borrows methods from both critical and inquiry dialogues. That is, scientific argumentation requires both the careful reasoning of inquiry dialogues in which individual claims are based on premises that cannot be refuted and the processes of critical dialogues in which arguments are debated and criticized.

This analysis suggests that 1) Classroom arguments could result in discussions that look vastly different, depending on the students' individual goals (do they want to disprove their classmates, work together to reach the "best" answer, or negotiate?) and 2) Achieving the instructional goals of sensemaking and persuasion may require multiple discussions in which the dialogue type shifts depending on the immediate goal.

Walton's taxonomy (1998) provides general descriptions but provides no systematic way to compare across dialogue types. I propose that there exists a set of discourse characteristics that could be used to compare across these dialogue types. That is, even with this variation, each of

Walton's dialogue types rest on the basic argument structure identified by Toulmin: an argument consists of justified claims, counter arguments and rebuttals. Thus, I suggest that each of Walton's disparate dialogue types share common discourse characteristics with different emphases. For example, counter arguments might play a large role in critical dialogues while they might be less apparent in inquiry dialogues. Understanding the argumentative discourse that emerges in discussions (including classroom discussions) requires identifying these common characteristics, because it is these characteristics that enable us to compare across discussions in order to understand the argumentative processes undertaken in each context.

In order to do identify these characteristics, I examine descriptions of classroom discourse that are characterized as representing a culture of scientific inquiry. Scardamalia and Bereiter (1994) refer to these classrooms as "knowledge-building communities" in which knowledge is seen as a product that can be tested, questioned and revised. De Vries, Lund and Baker (2002) identify "epistemic dialogue" as a key aspect of classroom cultures that encourage student participation in knowledge building. They define this dialogue saying "1. It takes place in a collaborative problem-solving situation. 2. It can be characterized as explanation or argumentation. 3. It is concerned with the knowledge and the concepts underlying problem solving rather than the execution of problem solving actions" (p. 64). Hogan and Corey (2001) also identify elements of a classroom discourse that align with the culture of scientific inquiry; for these authors, these elements include consensus building, peer review and revision as key aspects of this culture.

My present research combines this work with Toulmin's definition of the product of argumentation in order to define argumentative discourse as discourse with five characteristics:

1. Individuals participating
2. Individuals stating *claims*
3. Individuals *defending* their claims
4. Individuals attending and responding to one another's *claims and defense*
5. Individuals revising their own and other's *claims*

The italicized words indicate components of an argumentative product. As seen here, these components—the claims and defense of those claims—are the focus of the argumentative discussion. Figure 1.1 illustrates how these discourse characteristics relate to the three instructional goals of scientific argumentation, identified above.

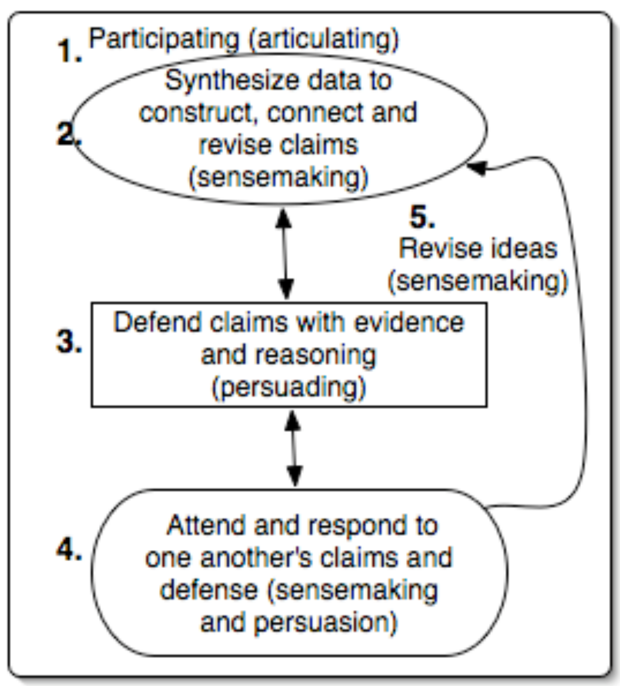

Figure 1.1: Characteristics of argumentative discourse aligned with the goals of the practice

These discourse characteristics extend the discussion above in which I identified the three instructional goals of argumentation by illustrating how classroom discourse can accomplish these goals. For example, aspect one, participation, relates to the goal of articulation. One demonstrates that they are articulating arguments by actively participating in the argumentative discourse. This aspect of the discourse is shown encompassing the others because one cannot fully engage in the goals of sensemaking and persuasion without first succeeding at articulation. The second aspect of argumentative discourse, constructing, connecting and revising claims indicates that students are making sense of the topic under study (represented by an oval in Figure 1.1). Similarly, one way to persuade others (represented by a rectangle in this figure) is to defend a claim (aspect 3)—to demonstrate why the claim is persuasive. The fourth discourse characteristic shown in this diagram is required for both persuasive and sensemaking goals (and is therefore represented as square with rounded corners). That is, one can neither revise their understandings in light of another argument nor determine whether they are persuaded by that argument without first attending to it. Finally, the fifth aspect of argumentative discourse—revising ideas—is shown in the arrow connecting attention to one another's ideas and sensemaking. This arrow represents that, in argumentative discourse, it is the attention to one another's ideas that prompts the revision of ideas. This revision can be a key part of reaching consensus through argumentative discourse, in the face of competing ideas.

Given that Walton's (1998) dialogue types differentially emphasize the instructional goals of scientific argumentation, I would expect them to differentially emphasize the various characteristics of argumentative discourse accordingly. For example, critical, negotiation and eristic dialogues emphasize persuasion. Thus, if the above framework is accurate, participants of these dialogues should be defending their claims and attending to the ideas of their classmates frequently. In contrast, inquiry, information-seeking and deliberation dialogues may reveal more emphasis on participants constructing their initial claims, attending to one another's ideas and revising their claims. Analyses of the argumentative discussions that emerged in this study (presented in Chapter 4) will elucidate the relationship between the instructional goals, discussion characteristics and dialogue types by interpreting the class discussions in terms of these analytical tools.

1.2 WHY IS SCIENTIFIC ARGUMENTATION CHALLENGING FOR STUDENTS?

Walton (1998) argues that dialogues in which participants engage are dictated by their expectations for how to behave and why to do so. I explore the challenges with fostering scientific argumentation in middle school classrooms by drawing from a growing body of research that focuses on the relationship between the practices and the expectations of the members of that community (e.g. Cobb, Stephan, McClain, & Gravemeijer, 2001; Lemke, 1990; Tabak & Baumgartner, 2004; Warren & Rosebery, 1996; Yackel & Cobb, 1996). Building on this work, I define a practice as an activity in which the community frequently participates and that evolves overtime. These practices communicate expectations regarding why participants are doing it (goals), how they should behave (interaction patterns or social norms) and the kinds of ideas that are valued (epistemic commitments). In short, this view holds that the practices of a community indicate the expectations of that community.

For example, in a classroom that relies on the traditional interactions that emphasize the teacher questioning and evaluating students, the teacher may be implicitly communicating that answers are accepted as correct—answers are valued—when they reflect the teacher's and textbook's knowledge regardless of whether students can explain how the evidence and conceptual understandings are connected. Similarly, these traditional classroom practices can communicate that the teacher's ideas are valued over those of the students and that students, therefore, have no reason to engage with their classmates' ideas.

I focus on two aspects of classroom practices that are related to the challenges students face when engaging in scientific argumentations. The first are the epistemic commitments that are communicated through the class discussions. As will be shown below, these are often contrary to the epistemic commitments needed to meaningfully engage in scientific argumentation. Second, I explore the social norms or "patterns of social behavior that [are] accepted in or expected of the class" (Horn, 2006, p. 9) of typical class discussions and those of argumentative discourse. Within this discussion I explore how the epistemic commitments and social norms influence student engagement with the five characteristics of argumentative discourse: participating, stating claims, defending claims, responding to one another's claims and defense, and revising ideas.

1.2.1 Epistemic Challenges

Much research has focused on students' epistemologies about science and how these beliefs can be revised through instruction and classroom activities (Lederman, 1992; Linn, Bell, & Hsi, 1998; Sandoval, 2005; Songer & Linn, 1991). This literature examines the students' beliefs about the types of knowledge that are valued as scientific, the types of questions that are worth investigating, and the ways to investigate and answer these questions. Much of the research in this area is based on the assumption that an individual's beliefs about science will influence how students engage in learning activities (Duschl, 2000). For example, some research has shown that students view scientific knowledge as a set of stable and isolated facts that they must memorize (Carey & Smith, 1993; Songer & Linn, 1991). This work hypothesizes that viewing science as a set of isolated, stable facts will mean that students' goal is to memorize the facts of the scientific world, rather than to make sense of that world with their peers. In this way, differences in the epistemic commitments of the scientific community and typical classrooms may cause difficulties with students' engagement in the fourth discourse characteristic of argumentation: attending to the ideas of others. In terms of Walton's (1998) argumentative dialogues, this view of science may tip students into an information-seeking dialogue rather than one of the more interactive ones that involve their knowledge construction. Thus, one challenge facing students as they engage in scientific argumentation is to develop a more sophisticated epistemology in which scientific knowledge construction is seen as a dynamic process of observations and iterative refinement.

In addition to understanding the dynamic process for constructing scientific knowledge, students are faced with learning new criteria for constructing and evaluating this knowledge. That is, constructing a knowledge claim in a way that is consistent with scientific inquiry requires that students connect the ideas to which they are being introduced with the evidence they have collected, and their prior conceptions and experiences (Driver et al., 2000; Jimenez-Aleixandre et al., 2000). D. Kuhn (1989; 1988; 2000) has found that students often struggle with this—they typically do not differentiate between evidence and inference. Instead, D. Kuhn argues that that students often ignore or re-interpret anomalous data in order to defend an erroneous claim. She concludes that students do not use the epistemological criteria of science—a reliance on evidence—and they are therefore likely to reaffirm their misconceptions. These findings led her to conclude that the alignment between claims and evidence, the revision of a claim in light of discrepant evidence, is a skill that students must learn. In terms of the aspects of argumentative discourse, a difficulty with aligning claims and evidence could result in student struggles with the second and fifth aspects: using data to construct claims and revising claims in light of new information.

Zeidler (1997) adds to this work by outlining seven key ways that students misuse data when constructing and evaluating arguments. Among these challenges are concerns that students use invalid or unreliable evidence, present the evidence in such a way that obscures the point and misinterpret or misrepresent anomalous data. Work such as this indicates that if we want students to engage in productive scientific argumentation then they must learn how to interpret and communicate the evidence—they must learn to use epistemic commitments surrounding evidence use in scientific communities (e.g., what counts as good evidence).

D. Kuhn (1989; 1988; 2000) and Zeidler (1997) both present these challenges with aligning evidence and claims as a cognitive skill that students lack and must therefore learn. However, alternative analyses of these same challenges hold that this may be more related to the classroom culture than a lack of specific skills. As stated by Cobb et al., “from this [alternative, more social] perspective, an individual student’s reasoning is framed as an act of participation in these normative activities” (Cobb, Stephan, McClain, & Gravemeijer, 2001, p. 119). That is, rather than assuming that the struggles identified by D. Kuhn (1989; 1988; 2000) and Zeidler (1997) stem from an inability on the part of the students, they must be understood in light of the normative activities of the community.

Cobb’s work (Cobb et al., 2001; Yackel & Cobb, 1996) examines the practices of math classes in order to identify the sociomathematical norms of the classroom community. “Examples of these so-called *sociomathematical norms* include what counts as a different mathematical solution, a sophisticated mathematical solution, an efficient mathematical solution, and an acceptable mathematical explanation" (emphasis in the original, Cobb et al., 2001, p. 124). In other words, Cobb et al. examine the classroom interactions in order to characterize the epistemic commitments most often communicated by the classroom discourse. This work is based on the theory that the discourse that occurs in a class is bound by the beliefs and norms that the community constructs and communicates through class discussions. That is, the ways individuals construct, defend and evaluate ideas are constrained by the epistemic commitments that are created through a history of class discussions in which participants develop an understanding of the types of answers and justifications that the community will accept and value.

Cobb's work (Cobb et al., 2001; Yackel & Cobb, 1996) highlights the idea that one's decisions regarding whether to defend an answer, how to defend and evaluate that idea grow out of the community. For example, imagine a math community in which knowing the "right" answer is valued less than explaining the procedure one used to get that answer and why that procedure worked. In a class such as this, it would not make sense for students to memorize and apply procedures out of their textbook. Instead, students would be pushed to understand the mathematical mechanisms used to solve problems.

Applying this work to scientific argumentation reveals that understanding why students do or do not justify their claims and/or use evidence requires that we examine the epistemic commitments of the community as they are used, developed and communicated through the classroom discourse. For example, it is possible that students in D. Kuhn's studies (1989; 1988; 2000) were operating under the assumption that common sense was a more valuable criterion for assessing their claims than evidence was. This assumption might be sensible to students when engaging in activities in which they are asked to make sense of an every day phenomenon, as were the students in these studies. Thus, it is possible that the epistemic challenges to scientific argumentation lie more in the communal expectations than in skills that students lack and must learn.

Researchers such as Suthers, Toth and Weiner (1997) examine this possibility by creating environments that emphasize the importance of using evidence to justify claims. Suthers et al. did this by creating a software tool that guided students in constructing “evidence maps” in which they linked their evidence and claims, labeling the connections between them (e.g., evidence ‘for’ or ‘against’ a claim). In this work, Suthers et al. found that students improved in their ability to differentiate between claims and evidence. Bell and Linn (2000) also designed a learning environment to improve students’ ability to use evidence when constructing knowledge through scientific argumentation. In this program, SenseMaker, students are provided examples of scientific arguments, have a visual representation of their current argument and evidence they have gathered, and can share their ideas with other students. Bell and Linn have demonstrated that work with this tool results in students that are able to construct sensible claims and defend them with warrants and evidence. These studies indicate that students’ arguments can overcome the challenges identified by Kuhn’s work (1989; 1988; 2000), when in an environment that values evidence.

Most of the analyses in this area, including the Suthers, Toth and Weiner (1997) and Bell and Linn (2000) studies, focus on the students’ final form arguments. Thus, while we see that the students’ argumentative products may increase in complexity and have explicit connections between claims and evidence, research has not yet addressed the relationship between the students' written arguments and their engagement in the discursive aspects of the practice. In other words, work such as this reveal students arguments improving but they do not necessarily examine student whether and how student discourse fulfills the characteristics of argumentative discourse identified in Section 1.1, and hence whether and how students are engaged with the three goals of scientific argumentation.

Berland and Reiser (in press) conducted a study that took a first step towards connecting the students' written work to their engagement with the goals of scientific argumentation. In this work, we found that, similar to Suthers, Toth and Weiner (1997) and Bell and Linn's (2000) studies, the students could use evidence to construct a claim. However, they did not consistently attend to the more social aspects of the practice—they did not persuade their audience of their claims. That is, in this study (discussed in more detail in Chapter 3), students consistently used evidence to make sense of scientific phenomenon and clearly articulated these understandings. However, about half of the students' written arguments wove the claims and evidence together thereby making it difficult for the audience to evaluate the claims in light of the evidence. Given the students' success with using evidence to construct their understandings, we concluded that the lack of attention to the evidence may stem more from challenges around the persuasive aspects of argumentation (such as attention to the audience) than from challenges with the use of evidence, itself. In other words, the students' challenges grew out of their expectations regarding the goal of the activity and types of answers that would be valued—their challenges grew out of their expectations regarding the epistemic commitments of the activity.

Kelly and Chen (1999) have made similar associations between students' struggles with argumentation and norms of the classroom community. In this study, they examined students' written arguments and found numerous challenges with the ways students employed evidence. These authors speculate that these challenges emerged because the culture of the classroom failed to emphasize the importance of evidence in argumentative discourse; in other words, the epistemic commitments most often communicated by the classroom discourse did not align with the epistemic commitments needed for scientific argumentation. Morgan and Beaumont (2003) contribute to this perspective through a study of students' argumentative discourse in an online environment. As they said, "when we analyzed these and other students' writing, it seemed that underlying many of the weaknesses was a failure to focus on the rhetorical aspects of argument—the forms of language that will be most effective in persuading an audience" (Morgan & Beaumont, 2003, p. 150). These and other studies (e.g. Hammer & Elby, 2003; Sandoval, 2005; Zohar & Nemet, 2002) contribute to a growing perspective that the epistemic challenges facing students as they engage in argumentative discourse can be accounted for by examining the epistemic commitments of the classroom, rather than the focusing solely on the skills involved.

1.2.2 Social challenges

Beyond the epistemic challenges, argumentation can be difficult for students because the types of interactions required for argumentation differ from those of a typical classroom. In particular, scientific argumentation necessitates that students have opportunities to discuss their ideas with one another (de Vries et al., 2002) and research reveals that these interactions are infrequent in typical classrooms (Lemke, 1990; Mehan, 1979; Weiss, Pasley, Smith, Banilower, & Heck, 2003).

Lemke (1990) provides insight into typical classroom interactions, in which he concludes that "activity structures" – patterns of who speaks, who listens and the types of things they contribute—provide an underlying set of "unwritten rules" or norms that regulate classroom interactions. These norms are the implicit expectations regarding how students will interact with one another, the teacher and the content under study. Comparing typical classroom activity structures to argumentative discourse reveals that typical classroom interactions can be in conflict with the interactions necessary for argumentation. In particular, typical classroom activity structures may inhibit student attention to one another's ideas—the fourth discourse characteristic key to scientific argumentation.

Recently, researchers have focused on the relationship between the triadic-dialog and argumentative discourse. Triadic dialogue occurs when the teacher asks a question, a student answers and the teacher responds to the answer given. Other authors refer to this as initiate-respond-evaluate or IRE (Mehan, 1979). This activity structure can limit student opportunities to substantively engage with one another's ideas. That is, in triadic dialog students talk to their teacher rather than to one another and therefore have few opportunities to engage with one another's ideas (Lemke, 1990).

Moreover, in an examination of power in a middle school science classroom, Cornelius and Herrenkohl (2004) found that the typical "evaluation" phase of the triadic-dialog or IRE exchange can limit student ownership. This is seen in Cornelius and Herrenkohl's work in a classroom in which the teacher focused on responding to student ideas by questioning and revoicing them rather than evaluating them. Students in this class exhibit high levels of ownership in both their post-interviews and their willingness to take and stand by positions during whole class discussions. This study reveals that when the teacher enables and encourages students to act as the content authority they are more likely to actively partake in the sensemaking discussions. Cornelius and Herrenkohl extend their study by considering the corollary: what happens to students' level of ownership and sensemaking during typical class discussions that foreground teacher evaluation? They contend that the evaluation phase means that students have less need to debate: if the teacher is the final arbiter of success, why should students care about their peers' opinions?

Similarly, Tabak and Baumgartner (2004) found that triadic dialogues limit students' need and motivation to substantively engage with their classmates' understandings. Tabak and Baumgartner illustrate this point by investigating the relationship between various teacher roles and students' authority and ownership over the content. In this work, Tabak and Baumgartner found that when the teacher took a "partner" role in which they worked side-by-side with students but were not the content authorities, students were more likely to challenge the teacher in substantive ways—thereby acting as a content authority who could construct understandings of the content—than when the teacher took a more traditional "mentor" role. Analyses such as this and that of Cornelius and Herrenkohl (2004) indicate that the prominence of teacher feedback in the triadic dialogue can limit students' ability to engage with one another's ideas because it removes their authority and motivation to evaluate and question them.

Across this literature we see the theme that typical classroom interactions provide students with little opportunity or motivation to engage with the substance of one another's ideas and consider whether they understand and agree with them. In other words, students rarely have reason to engage in argumentative discourse. Scardamalia and Bereiter (1994) are pioneers in designing learning environments that seriously address this challenge of creating classroom norms that enable and motivate students to engage with one another's ideas. Their work focused on transforming classroom discourse patterns so that students were actively engaged in communal knowledge building. While this work is not framed in terms of fostering arguments, their vision of communal knowledge building influenced the description of argumentative discourse that I provided in Section 1.1. As discussed there, Scardamalia and Bereiter's knowledge-building community is a classroom in which individual students work together, engaging with one another's ideas in a substantive manner, in order to reach a shared understanding. Scardamalia and Bereiter's work is based on the assumption that: "…it is not likely that imitation of surface forms can produce the radical restructuring necessary to turn schools into real knowledge-building communities" (p. 273). In other words, fostering students' substantive engagement with one another's ideas requires more than designing appropriate activities, one needs to change the norms of the community.

Brown and Campione (1996) make a similar argument in their work. Their design work focuses on "fostering communities of learners" (FCL) which are similar to the knowledge-building community of Scardamalia and Bereiter (1994) and the argumentative discourse on which I focus. In this work, they created a system of activity structures and design principles that work together to develop a "community of learners." The crux of their design lies in the systematic nature of their approach. Aspects of the FCL strategy do not work individually; in order to foster a community of learners one must implement FCL as a system, incorporating each element. Thus, this work highlights the complexity of substantively engaging students with one another's ideas. That is, similar to Scardamalia and Bereiter (1994), Brown and Campione conclude that creating a learning community in which students attend and respond to one another's ideas requires transforming the norms of the classroom community.

Combining the research endeavors of Scardamalia and Bereiter (1994) and Brown and Campione (1996), with the empirical studies discussed above highlights the social challenges that face students when engaging in scientific argumentation: typical classroom structures neither create opportunities nor motivate students to substantively engage with one another. In other words, typical classroom norms can inhibit students' ability to engage with the fourth discourse characteristic that is key to scientific argumentation: attending to one another's ideas.

The above discussion has identified a number of aspects of argumentative discourse that may be challenging to students. For example, students may struggle with revising their claims in light of contradictory evidence. In addition, the typical classroom norms may provide students with little motivation to attend and respond to their classmates' ideas. Given the relationship between the aspects of argumentative discourse and the goals of scientific argumentation, this analysis indicates that typical classroom norms will likely inhibit student success with articulation, persuading and sensemaking. In particular, if students rarely attend and respond to one another's ideas than they will have difficulty with both persuasion and sensemaking: they will be able to neither determine whether they are persuaded by their classmates' ideas nor build upon them in order to make sense of the phenomenon under study. Similarly, if students struggle with revising their claims in light of new evidence, they will have problems fulfilling the goal of sensemaking.

1.2.3 Why focus on argumentation in science classes?

The above discussion reveals that scientific argumentation is hard for students—in order for them to engage in this practice, the classroom norms must be transformed such that students have a reason to engage with one another's ideas and revise their ideas in light of new evidence. Given that many design endeavors have created learning environments in which students use evidence to support their claims, these challenges raise the question: is it worth it? Why work so hard to transform classroom practices in order to engage students fully in the persuasive and sensemaking goals of argumentation instead of being satisfied with students' partial fulfillment of these goals (as demonstrated by their ability to construct and defend initial claims) and success with the articulation of their arguments?

Broadly, the field of science education increasingly views science learning as participation in scientific practices (American Association for the Advancement of Science, 1990; Collins, Brown, & Newman, 1989; Lave, 2004; Lehrer & Schauble, 2006; National Research Council, 1996; Warren & Rosebery, 1996). As summarized by Lehrer and Schauble, a focus on practices means that we must examine science not only in terms of the product—such as students' understandings of scientifically accurate explanations—but also in terms of the "…ways of talking about phenomena and otherwise participating in a community of practice" (2006, p. 9). In other words, if understanding science means one is able to participate in inquiry practices than we cannot be satisfied with students' knowing explanations or writing arguments that include appropriate evidence. Instead, we must help students engage in the process of knowledge construction, through activities and social situations that make the practices of scientific inquiry meaningful and valuable.

Moreover, beyond being one of the practices of scientific inquiry, I see argumentation as the central practice. As stated by a recent synthesis of the research on how students learn science:

> To participate fully in the scientific practices in the classroom, students need to develop a shared understanding of the norms of participation in science. This includes social norms for constructing and presenting arguments and engaging in scientific debates. It also includes habits of mind, such as adopting a critical stance, willingness to ask questions and seek help, and developing a sense of appropriate trust and skepticism (Duschl et al., 2007, p. 40).

This conceptualization of science education places the goals of scientific argumentation at the center of the learning process. That is, engagement in the practices of scientific communities requires learning the skills of sensemaking (i.e., constructing arguments), articulation (presenting arguments), and persuasion (debating arguments).

In addition, while this focus on argumentative discourse adds an element of complexity to the classroom discourse—students must now do more than make sense of the science, they must engage with and evaluate one another's ideas—it is an important aspect of the knowledge construction processes. For example, Hatano and Inagaki (1991) hold that persuasive discourse makes discussions more engaging because it creates a need for the discussion; instead of simply talking about what happened, students are motivated to persuade one another of the accuracy of their own claims in order to reach consensus. In addition, this type of discussion can scaffold students' sense making by dividing the cognitive roles. That is, in scientific argumentation, participants focus on the different responsibilities of proposing, revising and evaluating the ideas at different times. Thus, throughout a discussion, an individual participant moves between presenting an understanding, evaluating other students' understandings and refining his or her understanding in response to feedback. Hatano and Inagaki (1991) have seen this division of responsibility create a natural forum for students to refine their original claims: "…in response to other parties' criticisms, most committed supporters could think of more plausible and sophisticated explanations than they had had at the beginning while maintaining a more or less consistent standpoint" (p. 340). This work reveals that the social aspects of argumentation—the argumentative discourse—are a key part of the students' knowledge construction process.

Similarly, as argued by Ford (2008), it is the critical goal of argumentation—persuasion—that enables students to engage in knowledge construction. If students are not empowered to criticize the ideas being discussed in a culture that values evidence, then they must accept the ideas that sound plausible and/or are held by the individual with the most clout (e.g., the teacher in a whole class discussion or a particular student in small group work). Thus, it is the goal of argumentation that enables students to engage in the inquiry practices of science.

1.3 Research Questions

The above discussion rests upon the expectation that classroom practices communicate expectations regarding the goals, interaction patterns and epistemic commitments and that these expectations will affect how students engage in future class activities. In other words, student participation in activities is constrained by the expectations that students have learned through participation in the classroom practices, up to that point. As such, this study is designed with the expectation that classroom communities will transform the practice of scientific argumentation in order to make it sensible in the context of the expectations that align with their typical classroom practices (e.g. Cobb et al., 2001; Engestrom, 1999; Lave & Wenger, 1991; Lemke, 1990; Tabak & Baumgartner, 2004; Warren & Rosebery, 1996; Yackel & Cobb, 1996).

This expectation aligns with Cohen and Ball's work in which they state that instructional interventions (such as the design work I do) typically result in "surface-level enactment[s], with adoption of highly variable selected elements" (2001, p. 76). In other words, classroom communities take up some aspects of the practices put forth in curricular interventions, but not all. In addition, Cohen and Ball found variation in which aspects each class adopts. Hogan and Corey (2001) provide an example of this adaptation of the practices in an instructional intervention. In their work, Hogan and Corey found that the traditional classroom goal of demonstrating individual success contradicted the scientific ways of reviewing a peer's work: the students in this study criticized one another's experimental designs but struggled with discussing the strength's of other's ideas. Hogan and Corey hold that this partial adoption of the scientific discourse illustrates a combination of the classroom and scientific communities' respective norms: the norms of the scientific community could be seen in the students' attention to one another's ideas (students took up this aspect of the intervention's practices) while traditional classroom norms were apparent in the students' unwillingness to implicitly critique their own ideas by praising those of a classmate.

Hogan and Corey (2001) call the resulting interactions a "composite culture" because they reflect a combination of traditional classroom expectations and those of a scientific community. In the present study, I refer to the resulting interactions as a "composite practice" because, rather than examining a classroom as they work with all of the practices necessary to form a scientific community, as did Hogan and Corey, I focus on a single practice: argumentation.

Walton's (1998) taxonomy (presented in Section 1.1) provides insight into composite practices that might form around the practice of scientific argumentation. For example, one class could interpret the practice as an opportunity to engage in a negotiation dialogue in which individuals compromise such that all students have contributed something to the final answer. In contrast, another class may engage in the argumentative activity as a critical dialogue such that the students attempt to disprove one another's claims. Walton argues that the argument dialogue in which participants engage is influenced by the social context in which the argument occurs (Kolstø & Ratcliffe, 2008). Thus, I suggest that these two disparate lines of research—philosophy of science and science education—converge on a single point: the social context (the immediate learning environment and the underlying goals, epistemic commitments and social norms governing the participants' behavior) will result in students' adapting the practice of argumentation in different ways. In particular, the practices in which the classroom typically engages will influence which of the argumentative dialogues makes the most sense in that classroom community.

The expectation that classroom communities will adapt the practice of scientific argumentation in order to make it work within their existing activity and goal structures raises the question that drives this research: What composite practices form when classroom communities take up the practice of scientific argumentation? This dissertation begins exploring this question through case studies of four classes as they enact lessons designed to foster scientific argumentation.

My analyses of these classes focus on two sub-questions:

1. How do classroom communities transform the practice of scientific argumentation?
2. Why do classroom communities adapt scientific argumentation in the ways that they do?

First, I explore how the participating classroom communities transform the practice of scientific argumentation. What characteristics of the practice will these students adopt and which will they adapt? Through this work, I look for variation in how classroom communities adapt this practice in order to understand the breadth of ways that they make the practice of argumentation meaningful. For example, it is possible that the argumentative discourse in one class will contain more aspects that fulfill the goal of persuasion than aspects focused on sensemaking. Alternatively, a class' discourse could emphasize sensemaking over persuasion. In terms of Walton's argumentative dialogues, it is possible that one class will engage in a critical dialogue, while another follows a more persuasive scheme. Exploring this question both lays the groundwork for understanding the composite practice that forms (it describes the composite practice found in each classroom) and creates a language and taxonomy for understanding the various ways students participate in scientific argumentation: it identifies the argumentative dialogues that emerge in classroom discussions and how these dialogues relate to the instructional goals of scientific argumentation. In addition, this exploration highlights the characteristics of argumentative discourse that are more and less common in science classrooms, thereby informing future work in creating environments that foster this practice.

The second research question works to explain the variation identified in the analyses for question one. As such, it explores why classroom communities adapt scientific argumentation in the ways that they do. I propose two possible factors affecting the class' adaptations of the argumentative practice: the immediate learning environment (i.e., the teacher strategies, curricular materials and activity structures) and the existing classroom practices. That is, beyond introducing the need to understand the breadth of ways classroom communities may take up this practice, the concept of a "composite practice" implies that the ways in which classroom communities adapt this practice will be consistent with the ways in which they typically interact.

As such, I should be able to find consistencies in the goals and epistemic commitments communicated by the interaction patterns of the non-argumentative and argumentative discussions in one classroom. For example, if students in one class adapted the practice by not responding to the feedback of their peers than I would hope to find patterns in their typical interactions that aligned with this discounting of student feedback. One possible such consistency would be if the teacher frequently evaluated the students' answers and ignored student evaluations such that students had no reason to worry about whether their classmate's agreed with them during typical class discussions.

I address these questions through a two-pronged approach. First, given that students do not typically engage in collaborative knowledge-building through scientific argumentation, I must use the best-practices put forth by relevant research to support teachers in facilitating this practice. Second, I need to study student engagement in the practice. For this study, I accomplished these goals through design research (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Edelson, 2002): I worked with a curriculum design team to create a middle school science unit that emphasized argumentation and then observed classes as they enacted the unit.

1.4 SUMMARY

This work will elucidate the relationship the typical classroom practices used in each class and the ways in which they transform the practice of scientific argumentation. Broadly, this research will test the assumption that there is a relationship between these two discourse contexts. In addition, details regarding how classroom communities make this practice meaningful and information about how typical classroom norms influence students understanding of and engagement in argumentation will assist in design endeavors to bridge traditional classroom norms and the goals of scientific argumentation.

In the following chapter I describe my research methodology in detail. I then present the design strategies used in this study in Chapter 3. Chapter 4 presents my analyses addressing question one: How do classroom communities transform the practice of scientific argumentation? And Chapter 5 addresses the second question: why do classroom communities adapt scientific argumentation in the ways that they do?

Chapter 2: Research Methods

The literature review presented in Chapter 1, introduces the expectation that classroom communities will adapt the practice of scientific argumentation in different ways, depending on the ways in which the students typically interact with one another, the teacher and the science content. This dissertation examines this expectation by exploring the composite practices that form when classroom communities take up the practice of scientific argumentation.

As discussed in Chapter 1, scientific argumentation is rarely found in classroom discourse (Lemke, 1990; Mehan, 1979; Weiss et al., 2003). As a result, examining how students engage in scientific argumentation requires that I work with teachers to create situations in which it is supported. Only then will I be in a position to examine how and why students engage in argumentation. To that end, I engage in design research methodologies (Brown, 1992; Cobb et al., 2003; Edelson, 2002) in which I both design learning environments to foster student participation in scientific argumentation and engage in empirical explorations of classroom adaptations of this practice.

Design research is conducted with two broad goals: 1) developing theories about learning and 2) refining and improving the learning environments. Cobb describes this process as involving

> an alternative view of the relation between theory and instructional practice in which neither is taken as primary. Instead, the basic relation is one of reflexivity in which the development of theoretical ideas is driven by and remains rooted in instructional practice that is itself guided by current theoretical ideas (Cobb et al., 2001, p. 118).

That is, design research methodologies are an iterative process for both building and testing curricular materials and/or teaching strategies and the development of theoretical understandings of learning (Brown, 1992; Cobb et al., 2003; Edelson, 2002). This approach emphasizes the importance of examining student learning in the context in which it occurs, because “there is no separation of knowing from that which is known; rather, there is an assumption that practice, meaning, and identity constitute and are constituted within context…” (Barab & Kirschner, 2001, p. 6). Thus, I use design research methodologies to provide an authentic context in which I can examine student engagement in (and therefore their understandings of) scientific argumentation.

In this chapter, I present my research methods. I begin my describing the data sources, providing detailed background information about each participating class. I describe the methods for analyzing the data from each class’ enactment.

2.1 DATA SOURCES

I observed four classes as they enacted an eight-week middle-school unit on ecosystems. (The design approach of this unit is specified in Chapter 3). Three of the enactments occurred in 2006 and one occurred in 2005. The teachers and/or school administrators volunteered to enact the curriculum and participate in the study. For each class in this study I collected: video-taped observations of two or three class periods a week for the duration of the unit enactment; teacher pre-interviews regarding their teaching experience and beliefs about inquiry instruction, group work and scientific argumentation; pre, during and post interviews of eight students per class regarding their content understandings, criteria for evaluating arguments, classroom norms, and the purpose of the activities being enacted; and all student written work. My analysis focuses on the videotaped observations and uses the interviews, where possible, to validate my interpretations of the classroom discourse. In the following four sections I briefly describe the four participating classes.

2.1.1 Mr. S.

Mr. S teaches in a self-contained 6th grade classroom from a K-6 charter school in the same large Midwestern city as the other schools. On its website and in signs around the building, this school reports having some of the most improved standardized test scores in the city. This achievement on standardized tests is a goal seen throughout the school and is made clear in the two classes with which we worked. For example, both 6th grade teachers in this school mentioned that the students had no time for science lessons until they completed the state standardized reading and math tests, in April. This is distinctly different from the other schools in this study, in which students attended departmentalized science classes throughout the year.

This school is in the middle of a rundown neighborhood known for gang presence and drug use. According to the principal, it was created to enhance the academic achievement of the typically underserved youth in the area. Wariness about the neighborhood is made apparent by the locked parking lot for teachers and staff. In addition, anecdotal conversations with teachers indicate that the 7a.m. to 5p.m. school day was initiated in order to provide two hot meals for students and to keep the students safe. 94% of these students are African-American and 89% participate in the free or reduced lunch program.

Beyond success on exams, this school has a clear focus on behavioral excellence and following the rules. For example, walking through the halls frequently reveals uniformed students standing silently in lines, reading books, while they wait for their turn. This school-wide focus on behavior is evident in Mr. S' class in which he consistently reprimanded students for speaking out of turn. Moreover, he was observed throwing out incomplete student work as punishment for them talking too loudly during group work. Thus throughout this school, and in our focus class, we see a heavy emphasis on students following the rules and school procedures.

Mr. S is an African-American man in his mid-twenties. He worked in sales before pursuing his teaching certificate. He completed his teacher certification program in January of 2006 and began teaching this class that same month. His enactment of the unit began about three-months into his teaching career. He is an eager and energetic teacher who clearly cares about his students. His dedication is evident in his decision to work at a school 1-½ hours from his home because he believes in the school's push for excellence in underprivileged students. Mr. S was certified to teach secondary social studies, and hired with the expectation that he would become the social studies teacher when the school departmentalized the middle school curriculum.

The sixteen students in Mr. S' class were known as the "stars" of the school. That is, there were two 6th grade classes and the principal reported that this one contained students who are excelling, while the other was made up of students that struggled with school expectations. Both 6th grade teachers openly discussed this distinction during informal conversations. However, in my infrequent observations of the non-focus class, I saw students engaging in in-depth and complex discussions, suggesting that the class differences may be more about behavior than academic performance.

Given Mr. S' background, the science content was new to him. The principal of the school asked us[1] to focus on this class, so we could support this more novice teacher. To that end, we assisted before and after lessons, helping Mr. S make sense of lesson plans and the content therein; we rarely interjected during the course of the lessons. As a result of Mr. S' challenges and difficulties acquiring equipment, the class did not complete the unit before the school year ended. Instead, this class did a combination of the first and second halves of the unit, concluding with the invasive species lesson described in Chapter 3.

The students in this class are eager to participate. During his pre-interview Ms S reported that his role was largely to rein his students in, controlling when and how they participated. During whole class discussions, Mr. S typically did this by asking a question and then identifying three to four students to answer the question. Unselected students frequently groaned when he passed them by. Between answers, Mr. S would evaluate whether the contribution made sense and potentially ask a clarifying question. He would then identify the next speaker, without validating the accuracy of the prior response. These conversations reveal students repeating one another's ideas with slight revisions with the apparent goal of contributing, regardless of whether their idea had already been introduced to the discussion. This eagerness to contribute is also evident during small group work in this class. During his pre-interview, Mr. S reported that he was uncomfortable with group work because of the students frequently got "too loud." He stated that he attempted to manage this by having clear expectations regarding students' voices and stopping the activity if they got too loud. This attention to the volume of the students'

[1] I followed three of the four classes in this study but another graduate student, Victor Lee, was primarily responsible for the data collection in this class. I assisted by meeting with Victor and Mr. S once a week to help the teacher prepare for the upcoming activities.

discussions in small groups lends itself to the characterization of both Mr. S as manager of who speaks when, and of the students as generally eager and excited to contribute to the discussion.

2.1.2 Ms. W

Ms. W teaches science to fifth-eighth grade students in a K-8 charter school, in the same school district as the other teachers in this study. Students apply to attend this school. Applications are based on residence and family history of attendance (they favor students who live in the neighborhood or who have siblings that attend the school). The school does not publicize their demographic information, but based on the teacher's report and researcher observations, it is clear that while large portion of the students utilize the free and reduced lunch program, many of the students' parents are professionals. Almost every student in this school is an African-American.

"The mission of … Charter School is to provide an excellent education for a representative group of urban students, while serving as a school development center for urban teachers" (school website). To that end, this school partners with local universities, serving as a research site to explore and try out new curricular resources and pedagogical strategies. This school has a 1:1 laptop program such that each middle school student leases a laptop for their personal and academic use. One of the research agendas of this school surrounds the use of laptops in the classrooms. This study did not use these tools; other than occasional note taking or web searches, the computers were typically off during the science class I observed.

This school has one class per grade, resulting in a tight-knit group of students that attend almost every class together. The class scheduled is organized in block periods such that most classes (including the science class I observed) met for 1½ hours twice a week and 45 minutes once a week. There were 30 students in the 6th grade class I observed. The students sat at large lab tables with four to five individuals per table. Students faced one another while sitting at these tables. As a result, there were always some students with their backs to the teacher.

This arrangement indicates the emphasis that the teacher, Ms. W, placed on students learning from their classmates. However, in her pre-interview Ms. W discussed challenges she has with group work at this school; unlike other schools at which she has taught, these students seemed resistant to actively engaging with one another through group work. Half of the students interviewed (four of eight) reported doing little group work in science class, and three of the four students that discussed group work mentioned that group work resulted in individuals each doing less work. That is, these students reported that group work created the opportunities for them to engage with the content less than they would during individual work or whole class discussions. This description matches Ms. W's frustrations; during the pre-interview, Ms. W talked at length about how the students at this school were less likely to substantively criticize one another than were students in the other schools in which she has taught.

That said, either due to the design of the curriculum or Ms. W's inclinations, almost every observed lesson included opportunities for students to work together. Group work consisted of doing research (using the internet and books), using worksheets to guide group discussion and sensemaking, and activities (such as using the microscope to observe microscopic organisms).

Ms. W has worked with researchers to design and investigate inquiry-based science curricula throughout her teaching career of more than twenty-five years. During a pre-interview she expressed feeling burnt out and ready to retire (she left classroom teaching at the end of the academic year in which this study occurred). Throughout her classes, Ms. W's attention to student thinking is apparent; she constantly deviates from structured lesson plans to follow student questions and ideas. This creates a classroom that is driven by discussion—discussion is both the vehicle through which Ms. W learns what her students are thinking and the locus of student learning.

During the pre-interview, Ms. W mentioned that her inquiry approach to science meant that there were no textbooks and that this sometimes resulted in her "lecturing" more than one might expect. Observations indicate that Ms. W's "lectures" consisted of her asking leading questions as she guided students to construct scientifically accurate understandings. Given her emphasis on student thinking, discussions often took much longer than outlined in the curriculum materials with which she was working. For example, when discussing whether a picture of a fish represented a living thing, the class spent more than five minutes debating whether the fish was in water. Typical of other discussions in this classroom, this one reveals students attending to the ideas of Ms. W and their classmates. In general, I characterize this class as having a feeling of "herding cats" as the teacher helps guide each individual student in the class towards a scientifically acceptable understanding.

2.1.3 Ms. B

I observed the third teacher, Ms. B, in two subsequent years. In both cases she taught in a grades 7-12 magnet school. This school is located a few blocks from a private university and the neighborhood is home to an affluent African-American population. Entry into this school is based on test scores in reading and math. The high school students are bused in from around the city while the middle school students are largely from the surrounding neighborhood. The middle school students seem to view this school as a "prep" school for getting into one of the city's "good" high schools (including this one, as enrollment in the middle school does not guarantee enrollment in the high school). About 95% of the middle-school students in this school are African-American and about 62% are on the free or reduced lunch program.

This school appears more similar to the experience of an urban high school than either of the other two sites. For example, it has metal detectors and security personnel at every entrance. While the middle school students are in a separate wing in which security does not have a heavy presence, it is hard to escape it. Moreover, the middle school maintains a "high school" feel with students moving freely from class to class on a bell schedule and being held responsible for themselves and their supplies in a way that is qualitatively different from both Mr. S' self-contained classroom and Ms. W's school in which all 6^{th} graders follow the same schedule.

Ms. B is a white female and she had been teaching for about five years when this study was conducted. She came to teaching through an alternative-certification program (through which she was certified as a secondary science teacher), after being a researcher in geriatric care. Through this experience, Ms. B learned the process of scientific inquiry first hand; as a teacher she tries to share that experience with her students. She received additional training through a university masters program, and is well versed in progressive, inquiry pedagogies. Moreover, she has participated in multiple design research activities both designing and enacting curricula.

Given this exposure, it is unsurprising that she constantly enacts inquiry-based science units that focus on student thinking. Ms. B responds positively when her students speak out of turn, initiating topics or responding to a classmate's idea. For example, during the pre-interview conducted in 2006, Ms. B talked about the importance of students coming up with the questions that the class investigated. That said, observations of her class indicate that the students do not consistently interact with one another and the content in this way. Instead, it is largely a teacher-centered classroom in which discussions consist largely of Ms. B asking leading questions in order to push her students to state the scientific ideas they are discussing, regardless of whether they constructed those ideas themselves.

These discussions often go in unplanned directions. This can occur at either the teacher's or the students' initiation. For example, during a pre-observation in 2006, the class began with Ms. B talking about calf hearts and veal. This was related to biology and stemmed from the dissection her eighth graders were doing that day. But it was not at all pertinent to this class' chemistry activity for the day. Similarly, in 2005, students frequently asked about socio-scientific topics such as HIV/AIDS and the 2004 tsunami. Ms. B would pick-up on the student questions and discuss the topic at length. In an informal conversation with me she mentioned thinking these were important discussions because they addressed student misconceptions about content that was relevant to their lives. These discussions reveal both her focus on students' understanding and her desire to share her expertise with her students.

I worked with a seventh grade class in the spring of both 2005[2] and 2006. Due to scheduling constraints, the majority of the students in both classes participated in honors classes in other domains. Thus, while the classes I observed were not technically honors, they may have had more academically successful students than other classes in this study. I describe the individual classes in the following sections.

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[2] In 2005, a post-doctoral fellow and I worked with this class.

2.1.3.1 Ms. B, 2005

In 2005 I worked with Ms. B and a post-doctoral fellow to redesign a precursor to the curriculum on which the 2006 study is based. Throughout this enactment, the post-doctoral fellow, Ms. B and I met weekly to discuss the previous week's lessons and revise the upcoming lessons in response to the students' and teacher's needs. This redesign was focused on using the design principles and strategies discussed in Chapter 3 to foster students' argumentative discourse. It is important to note that, while including this class adds an interesting depth to the data corpus, the data does not align completely because both the unit and interview protocols were slightly different across the year. These differences will be discussed, as relevant, in the analysis chapters (Chapters 4 and 5). I include the 2005 class in this study because the enactment in this class reveals adaptations of argumentation not seen in the other classes.

Students in this class were articulate and engaged in the material. Reviewing the videotapes shows that a handful of the fifteen students in this class seemed to help push the community to actively engage in sensemaking. To give a taste, one boy clearly saw himself as good at science, and, while his ideas were frequently incorrect, he constantly made contributions that were full of complex concepts. A female classmate of his countered him by participating less frequently but with more accurate ideas, while another girl in the classroom frequently got frustrated if the conversation (in whole class and small group discussions) strayed too far from the topic and would ask Ms. B for the "answer." These and other students helped create a classroom culture of high student engagement and participation.

2.1.3.2 Ms. B, 2006

Similar to the 2005 class, Ms. B's 2006 class contained sixteen students, many of whom took honors classes in domains other than science. However, these students were much less focused than students in 2005. In an attempt to help her students focus, Ms. B organized the seating chart for this class such that the eight girls sat on one side of the room and the eight boys on the other. The boys' side of the room was boisterous while the girls were typically quiet. In addition, many of the boys' contributions appeared to be made in a humorous way with the goal of eliciting laughter. While these jokes were often on topic and demonstrated accurate understandings, the contribution appeared to be made in order to make peers laugh, rather than to participate in the knowledge-building work of their classroom community.

In response to an emailed question regarding the differences between the 2005 and 2006 classes, Ms. B wrote: "The selection process [for entry into the magnet program] is flawed and the '06 cadre was not as mature, sophisticated, or prepared as the year before. What we think of as 'smart.' Whatever that means[3]." She also reported continued frustrations with these students as they entered eighth grade, the following year.

It appears that these student differences resulted in Ms. B facilitating class discussions very differently than she did in 2005 (her pedagogy is discussed at more length in Chapter 5). Typically, Ms. B had to push the students in 2006 much harder than she did in 2005, frequently prompting them for claims, justifications and questions. As a result, these discussions appeared to be more teacher directed with less explicit student sensemaking than they were in 2005.

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[3] Reprinted with permission.

As mentioned above, I include both classes in the analysis because the difference is instructive. While the curriculum is not identical across years, it is similar enough that it does not account for the teacher and student differences. Moreover, comparing the informal conversations in 2005 with her pre-interview in 2006 indicate that Ms. B's goals and teaching philosophy were consistent across the years. Thus, comparing the classes allows me to focus on the ways in which individual student differences affect the ways in which a classroom community takes up the practice of scientific argumentation (discussed in Chapter 5). In addition, the argumentative discourse seen in 2005 differs from all other arguments studied and, consequently, adds an interesting variation to this study (discussed in Chapter 4).

2.2 Analytical Methods

This thesis explores the conjecture that the goals and epistemic commitments revealed by the interaction patterns found in the typical classroom practices will influence how students take-up the practice of scientific argumentation. Consequently, my analyses must investigate these underlying aspects of the classroom practices during both typical and argumentative lessons. To do so, I use the interaction patterns found in these two contexts in order to infer the goals and epistemic commitments that they imply. This work assumes that the goals and epistemic commitments are implicitly communicated by the interaction patterns whether or not participants clearly articulate them in interviews. Consequently, the bulk of this analysis focuses on identifying the interaction patterns of the class discussions. In fact, the analyses presented in Chapters 4 and 5 focus on these interaction patterns, while the epistemic commitments and goals they imply are the focus of the final chapter, Throughout these analyses, I focus on the interaction patterns that are most relevant to scientific argumentation—the discourse patterns that entail the characteristics of argumentative discourse identified in Chapter 1 and reviewed in Figure 2.1. In other words, I engage in discourse analysis in order to determine whether and how the interaction patterns reflect characteristics of argumentative discourse. I use these patterns to understand the underlying goals and epistemic commitments of the students' discussions.

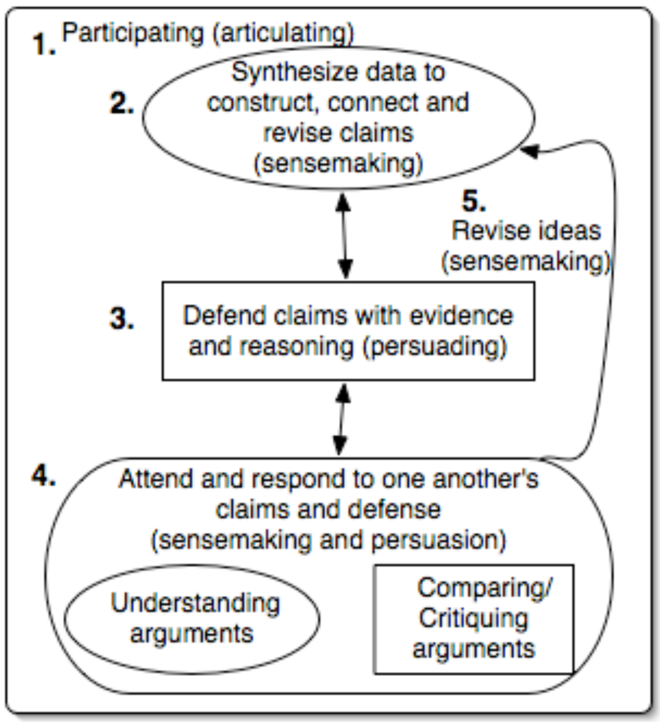

Figure 2.1: Characteristics of argumentative discourse aligned with the goals of the practice

Since the research questions investigated by this work examine how students argue, I focus on understanding their argumentative performance—their discourse—rather than their explicit statements of epistemology (i.e., the value of evidence in scientific sensemaking) or learning gains.

I analyzed the ways each of the four participating classes adopted and adapted argumentation by engaging in a detailed analysis of video taped observations of whole class discussions that were explicitly designed to foster argumentative discourse. Chapter 3 describes how these lessons were designed to foster argumentation. Chapter 4 explores the variation in how the different classes in engaged in scientific argumentation. In this chapter, I outline the levels of analysis and coding scheme used to examine whether and how student discursive contributions served argumentative functions (such as making and justifying claims), and the interactions that occurred around those contributions. That is, in this chapter, I elucidate how I looked at classroom discourse to understand student argumentation.

I used the same coding scheme to understand the discourse that occurred during both argumentative and typical (i.e., lessons that were not explicitly designed to foster argumentation) discussions. Using the same approach enabled me a compare across the lessons in order to explore how discussions in these contexts differed and how they were similar. To sample the typical discourse, I identified two three-minute intervals of every lesson in which argumentation was not a focus. In these lessons, students may have been asked to construct argumentative products (this is called writing ‘scientific explanations’ in the curriculum materials) as a way of reporting their understandings. However, the activity structures and problem contexts were not designed to enable or motivate argumentative discourse around these explanations. Thus, I identified these lessons as being examples of the “typical” classroom discourse that occurred in each classroom.

I chose to analyze three-minute intervals because they are large enough to enable multiple participants to make contributions and interact while being small enough to depict a discussion about a single, coherent topic. I used two of these three-minute intervals for each lesson to increase the sample size—to help ensure that the discussions I analyzed for each lesson were representative of the discussions that happened in each class, generally. I selected each three-minute time interval by identifying the middle of a whole class discussion about the lesson's topic. I then watched the video around that time-stamp in order to identify a coherent three-minute piece to transcribe. This resulted in a detailed transcript and analysis of six minutes (two three-minute intervals) of almost every lesson that was not designed to foster scientific argumentation[4]. Table 2.1 shows the number of "typical" lessons observed and the total number of minutes analyzed for each class.

Table 2.1: Dataset for examining typical classroom discussions

Teacher	Days used to examine typical discussions	Minutes of typical discussions analyzed
Mr. S	10 days	57 minutes (19 3-minute intervals)
Ms. B, 2005	10 days	60 minutes (20 3-minute intervals)
Ms. B, 2006	11 days	60 minutes
Ms. W	13 days	60 minutes

This approach—examining about 6 minutes from every typical class discussion observed—enabled me depict the typical class discussions. The alternative—examining one or two class discussions in their entirety—would have created an interesting point of comparison

[4] Not all observed days yielded two 3-minute intervals for two reasons. First, I did not analyze lessons that consisted purely of small group work and directions because my interest in this study is to understand whole class norms and the small group discussions varied too much by individual to inform that. In addition, some lessons only had one brief whole class discussion that was on topic; in these instances, I analyzed a single three-minute interval instead of two.

but it would have made it difficult to make valid claims regarding the representativeness of those discussions. Thus, while this approach resulted in my analyzing less of each lesson, it enabled me to see patterns across time (thereby reducing the effect of a single bad day or changes in the calendar) and content.

2.2.1 Coding Scheme

I developed a coding scheme that comprised the aspects of argumentative discourse that I and relevant literature (e.g. Erduran, Simon, & Osborne, 2004; Sampson & Clark, in press; Toulmin, 1958) have identified as key to the practice. I use the framework presented in Chapter 1 (and reviewed in Figure 2.1) to generate a coding scheme that captured student engagement with the goals of articulation, sensemaking and persuasion. In this section, I describe the coding scheme in depth. In Chapters 4 and 5, I describe how I use these codes to investigate the research questions.

I examine student work in each of the argumentative discourse characteristics identified in Figure 2.1 through a multi-step approach, developed through a combination of theory and data driven methods. Each step is outlined in Table 2.2 and described in more detail in the subsequent sections.

Table 2.2: Steps of the coding process

Step	Detail
1. Identify *knowledge-construction chunks*	Identify those sections of the discourse that were relevant, on task and entailed substantive discussion of topic (eliminating logistical conversations, review of previous material and off-topic discussion). Only the knowledge-construction periods were analyzed further.
2. Code for *utterance functions*	Identify the argumentative function of each utterance (e.g., contributing a claim, justifying a claim, etc).
3. Recombine utterances to examine *justification patterns*	Differentiate between those ideas (ideas can be expressed as claims, questions and evaluations) that are and are not justified
4. Recombine utterances to examine *interaction patterns*	Group utterances into interactions that code for how utterances are initiated (e.g., a student justifying a claim spontaneously compared to the teacher prompting for a justification), and who introduced the idea discussed (e.g., a student justifying their own claim compared to a student justifying a classmate's claim). This highlights the context in which utterances are made.
5. Combine interactions into *episodes* and identify the conclusion of the challenging episodes	Group interactions together to identify episodes, based on interaction patterns. Focusing on the episodes in which individuals challenge one another, code for how these episodes are resolved (e.g., the teacher answering the question compared to one of the participants changing their mind).

While my approach was a theory-driven coding scheme, it was refined through application to the data. Figure 2.2 represents the relative grain sizes of and relationships between each of these steps in the coding process.

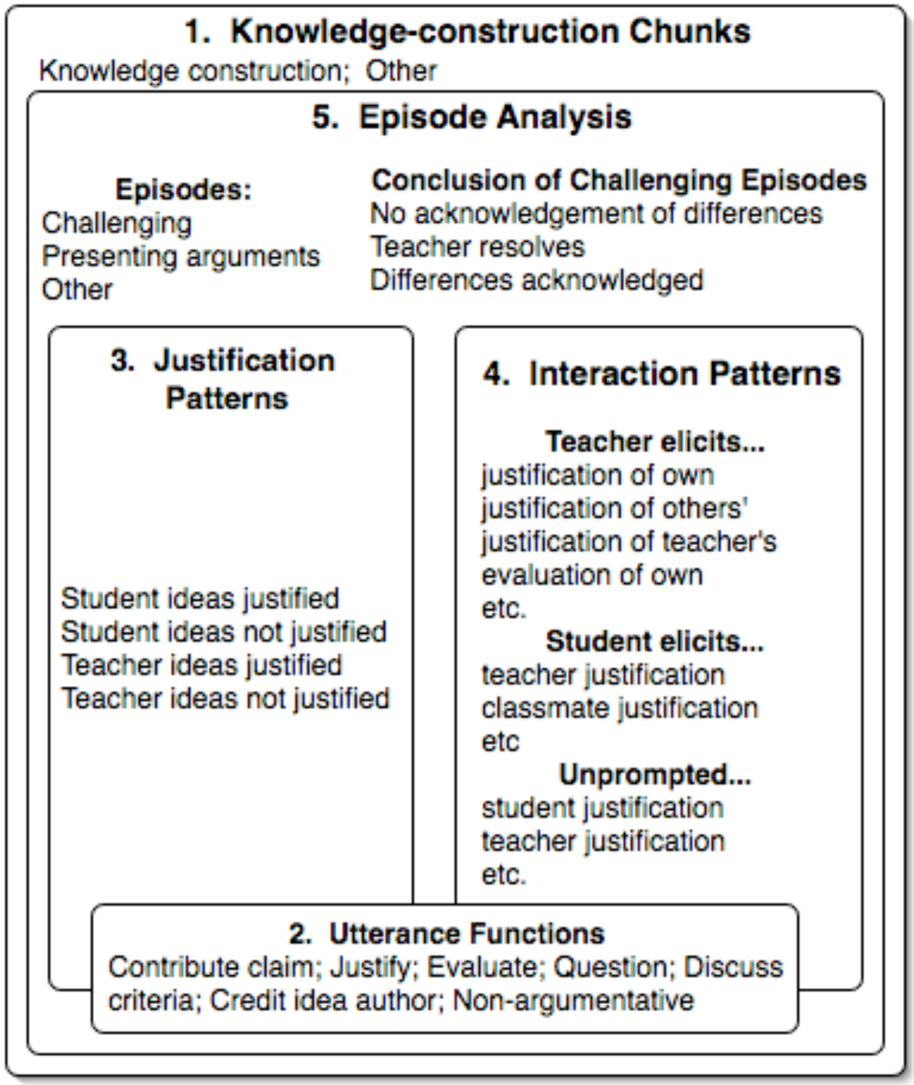

Figure 2.2: Schematic of the coding scheme

I describe the coding process depicted in Figure 2.2 in the remainder of this chapter. Chapters 4 and 5 will explicate how this coding scheme was used to investigate the research questions driving this study. The bold text in Figure 2.2 identifies the type of information coded for at that step in the process, while the normal text names sample codes (defined below) used at each step. The nested boxes indicate levels of analysis for each of the steps: justification and interaction patterns units are made up of utterances; episodes are made up of interaction patterns;

and chunks are made up of episodes. After step 1—identifying chunks—the steps identified in Table 2.2 move through the codes from the inside out on Figure 2.2. That is, after identifying knowledge-construction chunks, the analysis begins at the smallest level (i.e., utterance) and moves out to the largest grain-size (i.e., episodes). In the following sections I define each of these steps.

2.2.1.1 Step 1: Identify knowledge-construction chunks

As a first step in the coding process, I examined all videotaped observations in order to identify the large chunks of classroom discourse in which the whole class was engaged in conversations about the lesson content. Through this, I excluded the extended conversations that were review (e.g., discussing homework or other work done previously without connecting to the new content), logistical (e.g., discussing field trips, discussions of directions etc), a digression (e.g., discussing material that is tangentially related to the lesson), small group work and off-task. Those conversations that were substantive, whole class discussions of the lesson content were identified as "knowledge construction" and included for further analysis.

All chunks of discourse that were not knowledge-construction were removed from the data corpus. I made this choice because my purpose was to understanding how students interacted with one another, the teacher and the science content. The classroom interactions in which concepts were being reviewed, logistics discussed or digressions taken were therefore less informative than those conversations in which the students were engaged in figuring out new ideas. Small group work was also removed because, while interesting, these conversations provide insight into the way individual students interact with one another more than they illuminate whole class discourse norms.

Note that "knowledge construction" conversations often cover short digressions, logistical concerns and other non "knowledge construction" content. These are included in the "knowledge construction" data corpus because the goal was to examine entire conversations and removing utterances because they were not immediately about the content would eliminate this coherence. Overall, about 2/3 of the classroom discourse was coded as "knowledge-construction" and was therefore included for further analysis.

2.2.1.2 STEP 2: CODE FOR UTTERANCE FUNCTIONS

Analyzing the argumentative functions of student utterances reveals whether and how students fulfilled these aspects of an argument. As such, this analysis allows me to identify the argumentative functions that students frequently perform and those that are more challenging. Moreover, identifying the argumentative functions most often served and ignored by student utterances elucidates the sense that the classroom community made of the practice of scientific argumentation by clarifying whether students defended their ideas and how they responded to one another's ideas.

Table 2.3 summarizes the utterance functions I coded in this step of the process. Argumentative functions were determined in terms of the role an utterance plays in the discussion. In order to code the role of each statement, I focused on how the statement was received, in the conversation. For example, if a teacher said "okay" after a claim was made and the speaking student responded by providing a justification, I would code the "okay" as a "question" because the student interpreted the teacher's statement as a prompt for more information; regardless of the teacher's intent, the function the utterance performed was to elicit a justification. To do this, I coded each line in context, examining what proceeded and succeeded it, and, when in doubt, I gathered cues from intonation and body language from the video. In addition, if a single turn-of-talk fulfilled multiple argumentative functions (e.g., making a claim and justifying it in one turn of talk), it was divided into multiple utterances and each was coded. Thus, my use of the word "utterance" is not meant to indicate an individual's complete turn contribution to the discussion. Instead, it is closer to Gee's "lines," or "idea units" in that it communicates "one salient piece of new information" (Gee, 1999, p. 106).

Table 2.3: Argumentative function codes and their description

Function	**Description**	**Examples**
Claim	Instances in which individuals (student or teacher) contribute an idea that is taken up and discussed – questioned, revised, etc. Or, instances in which there are multiple answers to a single question.	• "And, I think it was part of a living thing" • "We think the invader eats grass"
Justifying	Instances in which individuals support the idea they contributed, or explain why some one else's idea is incorrect/needs revision. Here, 'idea' indicates any statement of an idea regardless of whether is presented as a claim. For example, questions and evaluations can be justified. Students can justify with: data, background knowledge, scientific principles, analogy, logic, inference or non-scientifically.	• "[Moving doesn't mean it is living] because a plant can be living but it don't move" • "[We think it eats grass] because the grass population decreased when the invader entered" • "[Question] How the invader keep going up? [Justification] you said if it eats rabbits, it would die out if it have nothing to eat [after the rabbits died out]."
Questioning	Instances in which individuals raise questions that push others to evaluate, revise, justify or extend their ideas.	• "Are you sure about that? I'm not saying you're right or wrong, I'm just saying are you sure." • "Why do you think that?" • "What do you think would happen if…?"
Evaluation	Explicit statements that assess the quality or accuracy of an individual's response.	• "That is a good question." • "Right." • "That makes sense."
Data	Descriptions of data without applying it to answer a question or justify a claim.	• "The graph is increasing." • "We found a stomach when we dissected the sea lamprey."

Criteria	Epistemological discussions about the process of argumentation and the criteria for evaluating arguments.	• "When you come up to present what are you going to use to make us believe that you are right?" • "What kinds of questions can we ask them to sort out whether they really have the right answer or not?"
Crediting author	Naming the original student author of an idea	• "So, Makaili asked a question that I remember on Tuesday about 'is there another way to look at this'" • "Do you think Jase might be kind of right saying…?
Non-argumentative	All other discourse that occurs when the class is making sense of the science (e.g., excluding off-topic discussion). For example, this includes: 1. Directions 2. Simple Questioning/Answering – questions and answers that are not taken up and discussed beyond typical IRE 3. Calling on some one to speak, bidding for a turn or other classroom management 4. Providing a minor correction (e.g., pronunciation, spelling)	1. "Would some one come up here and record the notes?" 2a. "What did we do yesterday?" 2b. "We dissected a sea lamprey." 3a. "Yes, [student name]?" 3b. "Can I go next?" 4. "It is pronounced sa-mon, not salmon"

In keeping with science education literature analyzing students' argumentative discourse (Erduran et al., 2004; Sampson & Clark, in press; Sandoval & Millwood, 2005), I used Toulmin's (1958) analysis of the generic argument structure to identify the primary argumentative functions that the student utterances could serve. As defined by Toulmin, an argument includes a claim that is justified by data, warrants, backing, rebuttals (explanations as to why a counter argument is invalid) and counter arguments (explanations as to why opposing claims are false). As my primary interests lie in understanding how students take up the aspects of scientific argumentation, I simplified his structure to focus on whether students were stating claims and justifying those claims without identifying the content of those justifications (e.g., whether students used data, warrants or backing to justify their claims). As seen in work by Erduran, Simon and Osborne (2004), the pass of differentiating between claims and justifications is a necessary step toward applying Toulmin's scheme in its entirety. Future work could examine the content of the justifications in this data corpus more closely in order to address questions of how students justified their claims. For my purposes, the single category of "justification" elucidates whether students are defending their ideas. The first two codes shown on Table 2.3 identify the codes that emerged out of this application of Toulmin's scheme: claim and justifying.

While my research questions allowed me to collapse data, warrants and backing into one category, they required that I differentiate between rebuttals, counter arguments and original claims. That is, in order to understand whether and how students participate with the fourth aspect of scientific argumentation—attending and responding to one another's ideas—I needed to capture whether students rebutted and contradicted one another. The functional analysis does not do this—depending on the way these utterances are used, this step in the coding process captures rebuttals and counter arguments as claims or justifications. The interaction pattern analysis (discussed in Section 2.2.1.4) differentiates between those claims and justifications that are made in response to a question and those that are made to contradict an idea that is currently being discussed.

Toulmin's structure focuses on the final form argument without offering much assistance in identifying functions that occur in argumentative discussions. I looked to Erduran, Simon and Osborne (2006) for help in identifying these more process-based functions. Their analysis was designed to analyze teachers' goals while supporting argumentation. Adapting this scheme to fit student and teacher discourse revealed four additional argumentative functions an utterance could play. An utterance could *question* or *evaluate* the ideas of another. In addition, an utterance could describe or interpret data without using it in defense of a claim. For example, in Ms. B's 2006 class, the students and teacher identified patterns in a graph (i.e., they determined whether the graph was showing a general increase or decrease across time regardless of smaller scale fluctuations). These interpretations were discussed before students made larger claims about what the fluctuations meant and were therefore a discussion of *data* before that data was employed as evidence to *justify* a claim (later in the same discussion, students used that evidence to justify a claim and this was utterance was coded as a justification). Finally, the discussion participants could discuss the epistemic *criteria* by which they were going to make their decisions. For example, a teacher may emphasize the importance of having evidence that supported the students' claims.

The final two functions identified in this coding scheme are *crediting an author* and *non-argumentative.* The first captures instances in which one person identifies the person who first stated the idea being discussed. Following Erduran, Simon and Osborne's coding scheme (2006), I identified these as a separate utterance function because they highlight a commitment to respecting students as the constructors of knowledge. That is, when a teacher identifies a student as the author of an idea, the teacher is ensuring that students get credit for their ideas.

The "non-argumentative" category is the most broad. My analysis was focused on those statements that were discussed in a way that indicated that science was something that could be debated; all other statements were coded as non-argumentative. In its simplest form, the non-argumentative code includes classroom management and managing speakers (e.g., students bidding for a turn or the teacher calling on a student). However, it also refers to content-rich statements (e.g., statements of review, lectures, answers to questions) that do not serve an argumentative function. For example, the typical IRE discussion, in which the students are asked to answer factual questions without explaining, justifying or questioning these answers, falls into this category. That is, content rich utterances in which the knowledge was treated as fact and is not problematized (Engle & Conant, 2002; Scardamalia & Bereiter, 1994) do not promote argumentation and are therefore coded as non-argumentative. Given this definition, many content-rich statements are coded as non-argumentative because they do not appear to foster additional utterances that fulfill argumentative functions. This broad category allowed me to group statements that serve many functions (e.g., classroom management, review, corrections) so that I could focus on differentiating between those utterance functions that the literature primed me to expect to be most relevant to argumentative discourse.

It is important to note that I did not enter into this expecting all utterances on the typical days to be non-argumentative. Any utterance that creates the possibility that the knowledge could be debated (utterances accomplish this by being followed by additional statements that expand, justify or question the idea), is coded as an utterance that fulfills an argumentative function. Thus, at least 50% of all the utterances in the knowledge-construction chunks fulfilled argumentative functions, regardless of whether the lesson was designed to foster student participation in argumentative discourse. These codes were applied to the typical discourse to look for relationships between “typical” classroom interactions and those that occurred when arguments were facilitated.

This functional analysis provides insight into the content of student utterances. It therefore is a step towards understanding whether and how student discourse fulfills the aspects of scientific argumentation. In particular, this step informs analyses of whether students are defending their ideas as well as the investigations into how students respond to the ideas being discussed (i.e., it differentiates questioning and evaluating the ideas discussed).

2.2.1.3 Step 3: Recombine utterances to examine Justification Patterns

While the functional analysis elucidates the frequency with which students make justifying statements, it does not elucidate the relationship between ideas and justifications. In the third step in the coding process, I focused on this relationship. In particular, I examined the discourse around each idea in order to determine whether it was defended (i.e., justified).

For each idea contributed to the discussion—for each claim, evaluation or question that expressed an idea that was new to that discussion—I looked through the discourse surrounding that contribution in order to determine whether it was justified. While the majority of student ideas were expressed as claims, some ideas were phrased as evaluations or questions to challenge another participant's ideas. In this way, justified evaluations and questions were coded as justified ideas, while unjustified evaluations and questions are coded as unjustified ideas.

Note that regardless of the length of time a single idea is discussed, this analysis codes it as a single "justified idea." For example, if a student presents a complete argument and is then questioned on his or her argument, the ensuing discussion is not coded as an additional "justified idea." Instead, the ensuing discussion is viewed as an extension of the students' argument. In addition, if multiple students justify a single claim it is coded as a single justified idea. Similarly, this step in the coding process focuses on the relationship between ideas and justifications rather than the time in which they were contributed. Thus, regardless of whether an idea was justified immediately after it was expressed or three turns-of-talk later it is coded as a single justified idea.

This approach allows the analysis to focus on the ratio between justified and unjustified ideas, regardless of the length of time given to each idea. Note that this distinction is non-obvious – sometimes questions will push presenters to defend a separate but related idea. Moreover, students often present the same idea as if it were new. I attempted to code these by "being true" to the participant's perspective—if the justification of a minor claim was taken as further support of the superior claim, I would not capture it as a new idea. However, if the presentation of the repetitive idea were taken as new, I would code it as such.

While this step collapses individual students into a single group, it does differentiate between students and teachers. The codes used for this step in the process include:

- Student unjustified idea—instances in which a student contributes an idea (in the form of a claim, question or evaluation) and never justifies it.
- Student justified idea—instances in which the students themselves defend an idea (regardless of whether the idea was presented by the teacher or a student)
- Teacher unjustified idea—instances in which the teacher contributed an idea without justifying it.
- Teacher justified idea—instances in which the teacher justifies an idea, regardless of whether the teacher or students initially contributed the idea.

Transcript 2.1, presented below after a fuller description of the coding process, provides an example of how all the codes—including the justification patterns—were applied to the data.

2.2.1.4 Step 4: Recombine utterances to examine interaction pattern

Step 4 focuses on one particular aspect of argumentative discourse (the fourth): students responding to one another's ideas. While the functional and justification analyses differentiate between student and teacher contributions, they collapse all students into the single category of "student." Consequently, these analyses do not inform analyses of whether students are responding to one another. The interaction codes examine this.

The interaction code does this by identifying the role of the initiator (student, teacher or none), the role of the speaker (student or teacher), author of the idea being discussed (own, other student, or teacher) and the function of the utterance. A partial list of these interactions includes:

- Unprompted teacher claim
- Student elicits teacher claim
- Student elicits student claim
- Teacher elicits student claim
- Unprompted student claim
- Unprompted student revises own claim
- Teacher elicits student revision of own claim
- Teacher elicits student revision of other student's claim
- Unprompted student revises teacher claim
- Teacher elicits student evaluation of teacher claim
- Unprompted student counter-claim of others

The entire list of interactions codes is greater than 70 items (it accounts for all possible combinations of how a contribution is elicited, the argumentative function being discussed, the speaker's role and the role of the author of the idea discussed), and proved unwieldy. That is, the list was so long, it was difficult to identify differences across classrooms.

While there are many slices one could take through these codes (e.g., looking to see what kinds of utterances the teacher elicits or comparing the relative frequency with which students justified or revised their own ideas to the relative frequency with which they justified or revised one another's ideas), the aspects of argumentative discourse identified in Chapter 1 focus on how contributions are elicited. That is, I am most interested in whether students are responding to one another's ideas. Thus, I simplified these interaction patterns by collapsing them to highlight how contributions were elicited (e.g., differentiating between student contributions that were elicited by a teacher prompt and those that were in response to a classmate's idea).

To examine this, I grouped together interaction patterns such as "teacher elicits student justification of own" and "teacher elicits student evaluation of own" into a single category: "teacher prompts." This category ignores the function of the utterance that was prompted and the author of the original idea being discussed. Four other categories are used in this scheme. These categories indicate interactions in which: students make an unprompted contribution (unprompted student); the teacher explicitly asks students to respond to a classmate's idea (teacher connects students); students respond to one another spontaneously (student responds to student); and interactions in which teachers make an argumentative contribution (teacher models argumentative discourse). Table 2.4 shows a subset of the interaction codes to illustrate how they are grouped together to examine how contributions are elicited.

Table 2.4: Depicts the categorization of the interaction patterns used

Interaction pattern	**Category**

Teacher elicits student justification of teacher claim	Teacher prompts
Teacher elicits student evaluation of own	
Teacher elicits student evaluation of teacher	
Teacher elicits student questioning of own	
Teacher elicits student questioning of teacher	
Teacher elicits student questioning of other students' idea	Teacher connects students
Teacher elicits student evaluation of other students' idea	
Teacher elicits student justification of other students' claim	
Unprompted student justifies own	Unprompted student
Unprompted student evaluates own	
Student justifies other's claim	Student responds to student
Student evaluates other's claim	
Student questions others	
Teacher justifies own	Teacher models
Teacher evaluates own	

As discussed above, student attention to the ideas of others can be seen in the difference between students' participating in response to a teacher prompt (teacher prompts), students engaging directly with one another (student responds to student) and unprompted student participation. In this way, these codes were designed to address my current research questions and alternative questions would have resulted in the interaction patterns being organized around different dimensions (Charmaz, 2003).

2.2.1.5 Step 5: Identify challenging episodes and their conclusion

Finally, I combined the interactions to form the largest chunks I analyzed—episodes. Episodes were used to look for patterns in the context in which individuals make contributions. For example, I examine whether students in one class are more likely to justify an idea when formally presenting their arguments or when challenging an idea. Comparisons such as this shed light on the context in which students engage in the various aspects of argumentative discourse. In addition, I use the episodes to examine whether and when students revise their understandings during an argument.

I identified episodes by grouping together neighboring interactions in which the content and interactions were similar. The codes I developed are a variation on the "main lesson activities" identified by Lemke (1990). While my episode codes are based on Lemke's activities, I revised his scheme for two reasons. First, I simplified it by removing codes. I removed codes that did not appear in the "knowledge construction" dialogue in my data set, and to merge his activities when the differentiation was unimportant to my analyses. Secondly, I extended his scheme when it did not address particular episode types important in the argumentation. For example, I highlight "challenging" as a stand-alone episode while Lemke's scheme folds it into a number of activities, depending on the interaction patterns (e.g., based on Lemke's scheme, challenging could occur in a triadic dialogue, student-questioning dialogue, true-dialogue or cross-talk).

Table 2.5 describes the episodes captured by my coding scheme. As seen in this table, teacher-questioning dialogue and student-questioning dialogue are both borrowed from Lemke's activity structures. Teacher exposition and giving directions are both extensions of his scheme. And finally, voting and challenging are additions to Lemke's activity structures.

Table 2.5: Types of episodes and their definition

Episode	**Description**
Teacher questioning dialogue	This episode is a combination of Lemke's triadic dialogue, board work, teacher-student duolog and external text dialogue and it represents the chunks of the classroom discourse in which the teacher drives the discussion by asking the questions.
Student questioning dialogue	This is also part of Lemke's scheme. It is similar to Lemke's triadic dialogue except that the student initiates the dialogue by asking the question and frequently responds to the teacher's answer by indicating whether it was understood. In this episode the student is driving the interaction rather than the teacher.
Teacher	This is a variation on Lemke's categories; it indicates the episodes in which

exposition	the teacher is speaking with only minor interruptions for classroom management or to respond to student's clarifying questions. I include Lemke's categories of Teacher summary and Teacher exposition under this heading.
Giving directions	This episode extends Lemke's scheme. It identifies the chunks of the dialogue in which the teacher gives students directions or highlights the expectations for how and what students will contribute.
Voting	One class in my data set used voting as a consensus building technique. This consisted of the teacher asking students who believed particular claims to raise their hands and be counted. As these interactions are not quite "triadic dialogues," I include them as a unique episode.
Presenting	In many of the classes in my data set, individual students or groups of students stood at the front of the room and formally presented their arguments with only minor interruptions from their teacher and/or classmates for clarifications and classroom management purposes. I call these episodes "presenting."
Challenging	Challenging episodes are those episodes in which an individual challenges another by asking a question, positing an alternative interpretation of the data, presenting counter evidence or simply stating disagreement. These are discussed at more length in the following.

I use the term "episode" rather than Lemke's "activity" for two reasons. First, my episodes are grouped according to both content and interaction patterns while Lemke's focus on the interactions. Thus, while my episodes would separate a teacher-questioning-dialogue that addressed two topics sequentially into two episodes, Lemke would identify this as a single activity. Second, I use "activity" in other places in this dissertation to imply longer periods of time in which students and teachers are engaged in a single task that is fulfilled through a number of episodes (of different types). For example, I use the term "activity" to refer to the Whole Class Debate (described in Chapter 3), which occurs through a series of student presentations, challenging episodes, teacher directions and triadic dialogue episodes.

The majority of these episode types (including teacher-questioning, student-questioning, teacher exposition, giving directions and voting) are not analyzed closely in this study. This is because the utterance, justification and interaction analyses capture the relationship between the discourse in these classes and student participation in argumentation. My analysis therefore focuses on the challenging episodes, which focus on the aspect of argumentative discourse currently, not addressed in the coding scheme: revision of ideas. The challenging episodes are those episodes in which one individual is challenging the ideas of another. Consequently, these episodes are prime places to look for this revision because they are the instances in which ideas are being most directly questioned and when alternative ideas are most clear[5].

Challenging episodes include at least two utterances such that an individual (either student or teacher) could question or challenge a participant's idea and that participant has an opportunity to respond to the challenge. If either of these steps is not included it is not coded as a challenging episode [6]. These episodes range from two utterances to more than twenty. Transcript 2.1 (shown below) provides an example of a challenging episode.

In identifying challenging episodes, it is important to note that not all questions are challenges and it is often difficult to differentiate between questions that are challenges and those that are not intended as such. For example, a teacher might prompt a student to justify his or her claim. This could be intended to prompt the student to contribute a more complete argument. Alternatively, this could be a challenge in that the act of identifying justifications (or the lack thereof) could prompt the student to revise his or her original claim.

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[5] To be fair, revision of ideas can occur in any of the episodes, but it is rarely made explicit and is therefore difficult to track. These challenging episodes are exchanges in which ideas are directly challenged so I expected them to offer students the most opportunity for explicit revision.

[6] The one exception to this rule occurred in Ms. W's class in which she both raised a challenge and responded to the challenge in a single turn-of-talk (coded as multiple functions in the functional analysis).

I resolved this difficulty two ways. First, if either the original arguer or the questioner explicitly acknowledged that they disagreed, than the episode is clearly one in which the ideas were being challenged. Secondly, I used the video to identify challenging episodes because the questioner and arguers respective intonations often differentiated between a question that was "challenging" and one that was clarifying or prompting for more information. These are admittedly limited indicators of "challenges" but, without knowing the speakers' intent, the intonation of their contributions and the responses they receive are the only indicators available.

While coding, I followed a rule of being as generous as possible. That is, traditional classroom interactions have relatively few instances of direct challenges—particularly between students. As my codes are designed to differentiate between traditional and argumentative classroom discussions, identifying more challenging episodes resulted in more interesting analyses. Thus, when in doubt about whether a question was meant to be a challenge, I coded it as a challenging episode. In a sense, this rule of identifying episodes as challenging as frequently as possible gives the participants the benefit of the doubt: as an outside observer I do not know the speakers' intents and when that intent is unclear, I assume they are engaging in an argument by disagreeing with one another.

After identifying the challenging episodes, I examined how each one was concluded. Focusing on the conclusion of the challenging episodes highlights instances in which ideas were explicitly revised in light of disagreements—this is a key aspect of scientific argumentation. Unfortunately, clear cases of revision rarely occur. Thus, I explored the challenging episodes in order to identify other ways that they ended—with or without actual resolution. For example, as will be discussed in Chapter 4, Mr. S' students were likely debate one another's points without resolving the differences, while Ms. B's students were likely to answer the challenges without acknowledging that the challenger disagreed with them. In neither of these classes was reconciliation and revision a common conclusion of the challenging episodes.

The conclusion types were logically generated and derived from the data. They were then applied across the data set. They break into two broad categories including episodes in which the disagreement is not resolved (including no resolution and the answering of the challenge without mentioning that the two parties disagree), and those in which the disagreement is resolved (including simply acknowledging it by agreeing to disagree, or revising and idea in light of the disagreement, or having the teacher resolve the dispute). The possible conclusions and a brief description of each one are included in Table 2.6.

Table 2.6: Possible ways to conclude a challenging episode

Conclusion Type	Description
No resolution	Challenge episodes in which no resolution is achieved are captured here. More often than not, this occurred when the students involved in the challenging episode went back and forth a few times until the teacher cut them off to move to the next topic or speaker.
Answered	In instances in which a challenge was phrased as a question, students would sometimes answer the question without engaging with the questioner. These were the hardest category to identify because challenges that are simply answered may sound like a non-challenging question and answer. I identified these using the tone of the questioners voice and the activity structure in which they were engaged (if the explicit goal was one of argument, I assumed that students were challenging one another when they asked questions).
Discrepancy acknowledged	In some instances students would acknowledge that they disagreed or that some justification was problematic to their claim, without explicitly revising their claim.
Revision	In other episodes, one or more of the participants with conflicting ideas would revise their claims or justifications in order to account for the points raised in the discussion.
Teacher resolves	In a classroom setting the teacher often resolves disputes between students, simply providing the answer or validating one of the arguments. Any challenging episode that the teacher resolved is captured with this code, regardless of how the teacher resolved it.

2.2.2 Example Transcript

In order to clarify this coding scheme, I provide a sample transcript with codes. This transcript comes from Ms. B's 2005 class in which they are arguing about the identity of an unknown animal in a computer-simulated ecosystem (see Chapter 3). In this lesson, students work with the computer simulation of a mini-ecosystem that contains foxes, rabbits and grass. Students observe population fluctuations that occur when an unknown organism, an invasive species, enters the ecosystem in order to determine the food source of this organism. Immediately preceding the exchange presented below, a group of four students presented their argument that the invader was a coyote that ate foxes. They supported this claim by describing the population fluctuations that they observed. For example one student said: "when the coyote population went up the fox population went down and when the fox population went up the coyote went down" (April 26, 2005 observation). They reasoned (incorrectly) that these fluctuations indicated that the fox ate the invader (the coyote) and the invader ate the fox. Transcript 2.1 picks up when a student in the audience questions this logic, wondering if it is possible for two organisms to eat one another. After some back and forth between the students, the teacher steps in and resolves this dispute.

#	Speaker	Quote	#2: Utterance Functions	3: Justify pattern	#4: Interaction Pattern	#5: Conclu-sion
1	Question-er 1	Wouldn't you think that a coyote or fox would be too small to eat a coyote unless it was dead?	Questioning	Student justifies (1.2) idea (1.1)	Student elicits (before transcript) student's own argument (1.1 and 1.2)	Teacher resolves (1.14)
2		And it had already. Yea. So I don't, I don't understand how a a fox and a coyote being alive, how a fox could eat a live coyote.	Justifying			
3	Presenter 1	Can you say that again?	Non-argument.			
4	Teacher	She is asking you: how can a fox eat a coyote?	Non-argument.			
5	Question-er 2	That is like a cat eating a dog	Justifying		Student elicits (1.1) just. (1.5) of others (1.1)	
6	Presenter 2	If it is alive	Uncodeable			
7	Teacher	But did you say the fox ate the coyote or the coyote ate	Non-argument.			

		the fox?				
8	Presenter 3	They ate each other. It is basically what gets	Non-argument.			
9	Teacher	They both ate each other? Okay.	Non-argument.			
10		Remember about life stages?	Claiming	Teacher unjustified idea	Student elicits (1.1) teacher claim (1.10)	
11	Students	Yea	Non-argument.			
12	Teacher	Like insect larvae vs. a big insect.	Non-argument.			
13	Presenter 4	It could be a baby.	Claiming	Student unjustified	Student elicits (1.1) student revision (1.13) of teacher's claim (1.10)	
14	Teacher	So maybe the fox ate the baby coyote.	Contribute idea	Teacher unjustified	Teacher revises (1.14) student claim (1.13)	
15	Student	That is nasty	Evaluative		Student evaluates (1.15) teacher (1.14)	
16	Student	That is cool. That is quite cool. Something eats something.	Evaluative		Student evaluates (1.16) teacher (1.14)	
17	Teacher	Keep going	Non-argument.			

Transcript 2.1: Sample transcript from Ms. B's 2005 Whole Class Debate about NetLogo

In Line 1, one student is asking a question of another. Line 2 is separated from 1 because it is a justification of the question. That is, the question includes the implicit claim that a fox could not eat a coyote and Line 2 provides a weak justification of that claim. Granted, Line 2 is largely a restatement of the claim, but the explicit statement that the argument does not make sense appears to defend the question. Thus two lines together are an instance of a student-justified-idea in that the student has articulated and justified an idea. These are given the interaction code of "student elicits student's own argument" because the question was prompted by the presenting students' argument (hence the student elicits) and because the content elicited was a justified idea – an argument.

Two lines of non-argumentative utterances in which the question is clarified follow the original statement of the question. Questioner 2 then further justifies the first questioner's claim that a fox could not eat a coyote. This is coded as a "student elicits student justification of others" interaction because Questioner 2 is responding to Presenter 1's idea by justifying the first questioner's utterance. After some more clarifications, the teacher enters the conversation, reminding students about "life stages" (Line 10). This is coded as teacher contributing a claim because it is taken up and discussed in subsequent utterances. In addition, this is an instance in which the students' questions prompted the teacher's claim. This is captured in the interaction code "student elicits teacher claim".

In Line 13, Presenter 4 takes the idea of life-stages to the next step—presumably this is where Ms. B was headed—suggesting that one of the organisms could eat the other while the prey was a baby. This is coded as "contributing a claim" because the student's suggestion is an example of a student making sense of the conversation, combining the teacher's suggestion of life stages with the question of how a coyote could eat a fox. At the interaction level this is an instance in which a student in responding to a student question (how could two organisms eat one another?) by revising a teacher's claim.

The teacher then revises and clarifies Presenter 4's claim. In terms of the justification pattern, both Ms. B and Presenter 4's contributions are unjustified. The teacher's utterance is also coded as a revision of the student's idea because the teacher's restatement slightly changes the meaning of Presenter 4's claim. This teacher contribution resolves the dispute—by revising Presenter 4's claim, the teacher has validated it and answered the original question. Thus, this entire exchange is coded as an example of a challenging episode that the teacher has resolved. The exchange concludes with two students' evaluating the teacher's contribution and the teacher asking students to "move on" (to the next discussion topic).

I provided this brief transcript and description of the analysis so as to make the above-described 5-step coding process concrete. This particular transcript was selected because it provided an example of a range of argumentative functions and interactions. It is not meant to be representative of the data set. Additional transcripts and their analysis will be discussed in subsequent chapters.

2.2.3 Additional Data

Beyond the classroom discourse, I gathered all of the available written work and conducted student and teacher interviews. The completion rate of the written work was such that it did not make sense to do systematic analyses of this data set. I use the interview data to validate my interpretations of the classroom discourse. In the following section I describe the data, protocols and analysis techniques for these interviews.

2.2.3.1 INTERVIEWS

Sample interview protocols are included in Appendix A. I interviewed each participating teacher before the enactments began in order to gather background data regarding the teachers' experiences, and values and beliefs about teaching and their students. These interviews are used to help describe each class—as seen above in Section 2.1 and inform my analyses regarding the existing classroom culture in each room (seen in Chapter 5).

Another researcher and I interviewed at least eight students in each participating class before the unit began, at key points throughout the enactment and at the conclusion of the unit. The interview protocol in 2006 was informed by the interview protocol in 2005 so there are slight differences across the years. In both years we asked students questions designed to access their explicit understandings of both the relevant content and the practice of scientific argumentation. In addition, the 2006 interviews were extended to include questions regarding the existing classroom norms. For example, as seen above, we asked students to report on the frequency with which they worked in small groups and whether they were comfortable sharing their ideas in class. As with the teacher pre-interview, the questions regarding classroom norms inform my understanding of the existing classroom cultures.

The post-interviews for 2006 were customized for each class. The purpose of these interviews was two-fold: 1) to identify how the students reacted to and understood the argumentative discussions and 2) to examine the ways that students constructed arguments in order to determine whether and how they supported their claims. Both of these questions inform analyses of the argumentative discourse that occurred in each class: the first can validate my interpretation of the students' goals in the argument and the second informs my analyses of whether and how the argumentative discussions supported students in revising their initial understandings. In order to accomplish these goals, the interviews were changed for each class so that we could ask questions about the specific lessons enacted in each class. In 2005 we only asked questions around the second goal identified above; we asked students to construct and evaluate arguments that were not aligned with the content discussed in class.

In addition to the pre-/post-interview sequence, we interviewed students throughout the enactment—with a particular emphasis on those discussions designed to foster argumentation. These interviews were altered to fit the context and content of the discussion highlighted in the interview, but focused on assessing the students' understandings of the argumentative process and the rationale for these interactions. I use these interviews in Chapter 4 to augment my interpretation of the argumentation that emerges in each class.

2.3 SUMMARY

In order to explore the composite practice that classroom communities develop around scientific argumentation and strategies for facilitating student participation in this practice I engaged in design research in which I both designed curriculum and worked with four classes as they enacted that curriculum. Through this work, I collected students' written work, participant interviews and videotaped observations of the enactments. The bulk of my analysis surrounds these observations and this chapter describes the analytical methods for exploring these observations. This analysis was a 5-step process consisting of:

1. Identify *knowledge-construction chunks*
2. Code for utterance *functions*
3. Recombine utterances to examine *justification patterns*

4. Recombine utterances to examine *interaction patterns*
5. Combine interactions into *episodes* and identify the conclusion of the challenging episodes

In the following chapter I describe the design of the curriculum materials enacted by each of the participating classes. In Chapters 4 and 5, I apply this coding scheme to answer the research questions driving this study, I describe this analysis process in each of these chapters.

Chapter 3: Design strategies

As described in the previous chapters, this dissertation explores the composite practice that classroom communities form around scientific argumentation As classroom communities do not typically engage in this practice (Lemke, 1990; Mehan, 1979; Weiss et al., 2003), I begin by working to foster student participation in scientific argumentation. To that end, I worked with the Investigating and Questioning our World Through Science and Technology (IQWST) research and design initiative in which we designed, enacted and researched middle school science curricula to support student participation in scientific practices (such as scientific argumentation) as they engage in project-based investigations (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2006). My work, and this research, focuses on the IQWST ecosystem unit *What Will Survive* (Bruozas et al., 2004). In this chapter, I describe the design approach and the specific activities that I helped create in order to facilitate student participation in scientific argumentation and that provided the context for my empirical studies.

3.1 Why is argumentation hard?

In Chapter 1 I introduced two categories of challenges facing students: epistemic and social. In this section, I review these challenges in order to identify the challenges the IQWST team addressed when designing to facilitate students' argumentation. In reviewing these challenges, I move beyond the literature discussed in Chapter 1 in order to introduce evidence that illustrates how these challenges manifest. This extension better motivates the design strategies described in Section 3.2.

3.1.1 Epistemic challenges

Literature examining students' epistemologies about science has found that they often view scientific knowledge as a set of stable and isolated facts that they must memorize (Carey & Smith, 1993; Songer & Linn, 1991). Moreover, this view of science as stable isolated facts can be reinforced by traditional classroom instruction: the typical interactions in a science classroom support this view of science by presenting it as a positivist domain in which the evidence leads to an incontrovertible truth that the students must memorize (e.g., Driver et al., 2000; Lemke, 1990). If science is a set of facts to learn, then the goal is to demonstrate individual mastery over that information—not to argue and revise one's understandings (Hogan & Corey, 2001). Thus, one epistemic challenge to argumentation is that traditional classroom interactions may communicate epistemic commitments that do not motivate student participation in argumentative discourse.

In addition, students struggle with constructing knowledge in a way that is consistent with scientific inquiry. Constructing claims in a scientific manner requires that individuals connect the scientific ideas to which they are being introduced with the evidence they have collected, and their with prior conceptions and experiences (Driver et al., 2000; Jimenez-Aleixandre et al., 2000). D. Kuhn (1989; 1988; 2000) has found that students often struggle with this—they typically do not differentiate between evidence and inference. Instead, they revise their interpretations of the evidence or ignore the disconfirming evidence such that they do not need to revise their understandings of the concepts under study. Consequently, students do not reliably base their knowledge claims on the available evidence. If students do not use the epistemological criteria of science—a reliance on evidence—they are likely to reaffirm their misconceptions. Thus, if we want students to engage in productive scientific argumentation, they must learn to value the available evidence, using it as the primary criterion when evaluating one another's knowledge claims.

Pre-interviews with the students in this study illustrate this epistemological challenge. This portion of these interviews was designed to determine the criteria students used to reconcile disagreements. This relates to the above challenges with evidence because the disagreements are prime instances for students to use evidence in order to make sense of something. That is, it is hoped that students would reconcile their different opinions by evaluating the alignment between each understanding and the available evidence. However, D. Kuhn's work (1989; 1988; 2000) predicts that these students would use other criteria such as appealing to authority or plausibility.

The students discussed here are from Ms. B's 2005 class. She frequently encouraged these students to use evidence to make sense of their experiences—both before and during the enactments of IQWST units. Beyond illustrating the challenges that students face with using evidence during argumentative discussions, these interviews reveal that the student epistemologies and the interaction patterns are intertwined, thereby supporting the claim I made in Chapter 1—class discussions influence the epistemic commitments with which students approach problems—and motivating the design strategies presented in Section 3.2.

When describing what happens when students disagree about an idea in science class, one student said:

> Student R: "We say our opinions, if we still don't agree, we ask Ms. B." (Pre Interview, 03.09.06, 00:06:25)

In this response, Student R reports asking her teacher, the authority figure, to resolve disputes with her classmates. Student K refers to a similar method:

> Student K: "I don't really change my mind easily. You have to have a lot of stuff to say, a lot of evidence. And, I have to know it is right, you have to ask Ms. B. if everything they're saying is right" (Pre Interview, 03.09.06, 00:09:15).

These interview fragments reveal the complexity of the epistemological aspects of scientific argumentation. In the first, Student R demonstrates a reliance on her teacher. This student does not mention evidence or data as being a relevant criterion for resolving disagreements. Student K has moved beyond Student R. She begins by stating that her classmates must have evidence to convince her of their ideas. In this way we see that she is moving towards the epistemological criteria of the scientific community. However, she then reverts to criteria similar to that of Student R: the teacher's approval.

Thus, in both of these interview snippets, we see the students focusing on their teacher to resolve disputes, rather than the available evidence. This is an example of an epistemological challenge for engaging in argumentation: the students are using a different set of criteria to resolve their disputes than scientists do. Moreover, similar to D. Kuhn's findings (1989; 1988; 2000), Student K's interview reveals that students must also learn how to evaluate evidence. It is likely that the criteria they are using is sensible: students are learning about the topic being investigated so they have little reason to trust their interpretations of the data when their teacher offers alternatives. However, regardless of the source of the challenge, these examples indicate that students may struggle with the primacy of evidence when engaging in scientific arguments.

How do we design curricula with the goal of affecting the epistemic understandings that students use in science class? How can we help students believe that scientific knowledge is a malleable system of ideas that are constantly under revision? How can we influence students to rely on evidence as they construct these ideas? Much work has been done explicitly discussing these beliefs and providing students with historical examples that demonstrate the point (e.g. Lederman, 1992). Research in this vein presents evidence of the students' explicit epistemologies about science changing and concludes by emphasizing the importance of learning experiences that make the epistemological aspects of scientific inquiry explicit (Duschl, 2000). However, there is little evidence that this explicit focus influences student participation in scientific practices, such as scientific argumentation (Kenyon & Reiser, 2005; Sandoval, 2005). In fact, building on the situative perspectives of learning (discussed in Chapter 1), reveals that the social situations of the classroom—the interaction patterns—communicate epistemic norms that may or may not align with those of the scientific community. Thus, we must go beyond telling students about the epistemic beliefs that more closely align with the scientific community; we must put them in social situations in which these beliefs make sense.

This view aligns with the "epistemological resources" view (Hammer & Elby, 2003; Loucas, Elby, Hammer, & Kagey, 2004) that proposes that students hold multiple epistemic perspectives each of which can be activated in different contexts. For example, while Student K indicated that she relies on her teacher to resolve disagreements in the classroom, it is likely that she turns to evidence or experience to resolve disagreements in everyday contexts—such as arguments that occur with her friends. The "epistemological resources" perspective suggests that, rather than teaching students new epistemic perspectives, teachers and designers should "think instead of helping students 'find' and apply productive resources they use in other contexts but fail to activate in science class" (Loucas et al., 2004, p. 59).

That is, in order for students to engage in a classroom discourse that more closely aligns with scientific argumentation, the context in which they are working must activate epistemic resources that the students may not typically use in science class. For example, traditional classroom norms, in which the students' goal is to acquire the knowledge held by the teacher and textbooks, support students working with scientific knowledge as if it were a set of isolated facts to be memorized. Moreover, this goal structure may explain the results of the above interview: if the students' ultimate goal is to acquire the accepted expert understanding then it is sensible for them to turn to an authority, instead of the evidence, when resolving disputes. Similar interpretations could be made of D. Kuhn's results (1989; 1988; 2000): maybe these students struggle with aligning their claims and evidence because they are in a context that rewards them for immediate accuracy rather than encouraging them to revise their ideas in light of new evidence. In contrast, an epistemological stance that would be more consistent with scientific argumentation would emphasize the learner's ability to construct knowledge and the importance of evidence when doing so. As argued by Loucas et al. (2004) students use both of these resources—both knowledge as truth and knowledge as something to be constructed—in other contexts. Thus, rather than telling students that scientific knowledge is constructed by examining the evidence, the challenge to designers is to create situations that help push students into using their pre-existing knowledge-is-constructed stance. We must put students situations in which it makes sense for them to construct their own understandings using evidence.

3.1.2 Social challenges

Beyond the epistemic challenges, argumentation introduces new social processes in which participants discuss their differing viewpoints and the reasons to believe each side. Engaging in this type of persuasive discourse requires that individuals attend to the thoughts of the other individuals in the argument. In addition, engaging in argumentation requires that individuals present their own arguments in a way that allows their audience to evaluate them. Unfortunately, the “unwritten rules” (Lemke, 1990) of a classroom often inhibit student engagement in argumentative discourse.

For example, the predominance of classroom interactions in which the teacher asks a question, a student answers and the teacher responds to the answer given (IRE) (Mehan, 1979) or triadic dialogue (Lemke, 1990) largely prevents students from engaging in student-to-student discussion (Hatano & Inagaki, 1991; Lemke, 1990). This interaction style neither enables nor necessitates that students build upon one another’s contributions. Furthermore, even when working in small groups, students often fail to engage in productive argumentation and instead, look to the most “capable member” for the desired answer (Barron, 2003; Hatano & Inagaki, 1991). Thus, in typical classroom interactions, students have little opportunity or motivation to understand the substance of one another’s ideas, nor consider whether they understand and agree with them. In this way, typical classroom interactions may inhibit students’ engagement with the social aspects of argumentative discourse.

These challenges with attending to the social dimensions of argumentation are apparent in how students engage in the practice. For example, in earlier work, we (Berland & Reiser, in press) presented an analysis of students' written work that revealed students struggling to engage in the social dimensions of argumentation. In the following, I present two examples of student work on the final project in this study. I use these to illustrate the ways in which students' written work reveals their engagement (or lack thereof) with the goals of argumentation (i.e., articulating, sensemaking and persuading) and, in particular, the socially oriented goal of persuasion. These examples came from the culmination of a two-week project in which the students investigated a computer database containing information about the population of finches, on the Galapagos Islands (Reiser et al., 2001; Tabak, Smith, Sandoval, & Agganis, 1996). Students were asked to work in pairs in order to interpret the computer data and determine why a majority of the finches died during the dry season of 1977, and why some were able to survive. In order to answer this question, the students had to use data to identify trait variations that enabled birds to differentially survive the drought. This complex data set supports multiple plausible interpretations. For example, one response could state that the birds that survived the drought had longer beaks, enabling them to crack the harder seeds that also survived the drought. Another plausible argument that is consistent with the data (but less accurate scientifically) is that the birds that weighed more had fat stores, making them better able to survive the food shortage that resulted from the drought.

In the following example, the students present a coherent account that is based in the available data. We determined that the student authors of this explanation had succeeded at articulating and sensemaking because their argument presents a clear explanation of their understanding that was clearly consistent with the available data. However, this written argument does not reflect the third aspect of argumentative discourse—it does not show a clear defense of the students' claims. Thus, it appears that these students were not successful with the goal of *persuasion*. That is, when constructed in this way, the students' argument does not enable the audience to evaluate whether their claim is supported by evidence; rather than defending the claim by explicitly stating the evidence, these students have embedded their evidence with their inferences in a narrative account of what happened and, as such, the students' evidence is indistinguishable from their claims.

> The rainfall decreased a lot which created the plants to not grow as much, so the Chamae, Portulaca, and Cactus had softer seeds so birds fought in competition for those plants. Since those plants were very scarce there was one other plant called the Tribulus, which had harder and lengthier seeds so the best chance for survival was to adapt[7] to the Tribulus and be able to eat the seeds without dying (Classroom 1, Student Group JH, Finch Survival)[8].

By embedding the evidence in their explanation these students have made it difficult for readers to identify that evidence. Without being able to differentiate the evidence from the students' claims, readers are unable to determine whether the explanation is scientifically accurate. That is, while the reader can determine whether the authors' claim matches their own understanding of the phenomenon, or is plausible, an unfamiliar reader cannot determine whether the students' work accurately represents the data.

Student authors of arguments such as the above are not explicitly using evidence to persuade their audience because they are not helping their audience differentiate between the

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[7] These students are clearly not using "adapt" in the strictly scientific sense. Based on conversations with these and other students, we believe that students J and H are saying that the birds changed what they ate, not that their physical characteristics were changed.

[8] Throughout the student quotes I corrected the spelling of the plant names (for clarity to the audience) but left the rest of the student grammar and spelling as written.

inferences and evidence in their explanation. In keeping with D. Kuhn's work (1989; 1988; 2000), it is possible that this lack of differentiation stemmed from the students' lack of understanding regarding what evidence is and how to use it in scientific inquiries, rather than inattention to persuasion. However, we found that all the written arguments in this dataset, even those explanations that exhibited ambiguous evidence, were in fact constrained by the evidence they investigated. This suggests that these students were attending to their interpretations of the evidence in developing their explanations, thereby revealing that these students were able to use evidence in productive ways.

Thus, rather than an inability to distinguish between inferences and evidence, we suggested that students' observed difficulties with evidence and inference stemmed from relative inattention to the goal of persuasion. For these students, their understanding of scientific explanations may not have included a central role for persuading an audience of their explanation. Instead, their sense of the purpose of their written work may have been to demonstrate that they knew the "right answer." Alternatively, if these students did think of their peers as a potential audience for their explanations, they may have viewed them as an audience that was familiar with the data, and therefore did not require carefully elucidated claims and evidence. I suggest that, unless students genuinely took on the goal of trying to persuade others who didn't already know what they knew—why their claim is supported by evidence—there is little motivation for them to go beyond presenting the story they thought correct. Instead, they were treating the evidence as common knowledge that all students shared. According to this view, students who produced explanations ambiguous in their evidentiary support were attempting to demonstrate an accurate understanding, without attempting to convince their readers that their causal account aligned with the available scientific support. In this way, it appears that these students have not fully engaged with the aspects of scientific argumentation: they have not used the available evidence to defend their claims. They therefore have not attempted to *persuade* their readers of the accuracy of their explanation[9].

In the second example, similar to the first, the students presented an explanation that demonstrated their success with the sensemaking and articulation goals. However, it appears that the students are more engaged with the *persuasive* goal of argumentation than were the student-authors of the first example; the structure of this written argument clearly reveals aspect three of argumentative discourse in that the claim is clearly defended with evidence. Thus, this construction of a written argument allowed the students' readers to determine whether they were convinced that the claim accounted for the available data. In this account of the finch mystery, these students correctly claimed that some birds survived because they ate a specific plant—the Tribulus. Unlike students in the first example, after stating this claim, these students went on to defend it with supportive evidence and reasoning:

> We believe that the reason some of the finches survived was because they ate the plant that was able to survive without water called Tribulus. The charts of cactus, Portulaca, and Chamae all show a major decrease to zero, from wet '73 to wet '77 except for the Tribulus plant. The Tribulus plant decreased quite a lot but not enough to disappear all the way. It survived after the drought in the dry season in '77. The research of four birds that survived showed that they all ate Tribulus. Which means that the drought didn't effect the Tribulus plant, which didn't effect

[9] It is also possible that these students have engaged with the social aspects of argumentation but that their epistemic criteria is different enough that we do not recognize it. That is, these students could have been using criteria other than evidence to persuade their audience of their claim. For example, they may have been using plausibility instead of evidence to persuade their reader. In this case, one might conclude that the students are struggling with the epistemic aspects of scientific argumentation while they were engaging with the social aspects. I address this possibility in following sections.

> the ground finches that ate it. According to the information we found, our hypothesis is correct. They both said that the Tribulus was the best surviving plant of the drought in '77, which didn't effect those who ate it (Classroom 1, Student Group QT, Finch Survival).

As with the first explanation, the authors of this second example have used evidence to construct a plausible account of the finch mystery. However, the difference in presentation across these two argument types implies that the students in the second defended their claim; by explicitly presenting their evidence, these students have enabled their audience to determine whether the evidence supports the claim. In this way, the students have taken up the persuasive goal of argumentation: rather than writing to a teacher that knows the answer, these students seem to be persuading their audience that their explanation is correct.

Comparing these two responses to the finch mystery highlights one of the social challenges to argumentative discourse. One interpretation of the first explanation is that the students' apparent goal was that of a typical classroom: they seemed to be demonstrating the acquisition of the teacher's explanation. However, the students in the second explanation moved beyond the presentation of an explanation in order to persuade their audience of their scientific accuracy. In this way, the authors of the second explanation have taken on the social challenges of argumentation by actively engaging in the persuasive goal of argumentative discourse.

The above discussion illustrates one way that social challenges to argumentation can manifest in student performance. How do we design curriculum that helps students attend to the social aspects of argumentation? As we have seen in the literature, we must do more than tell students to talk to one another, instead of the teacher (Hatano & Inagaki, 1991; Hogan & Corey, 2001). As stated by Herrenkohl, Palincsar, DeWater and Kawasaki "Given that much of schooling involves teacher-directed activities and discussions, it is not surprising that we have observed that students do not spontaneously ask questions of each other when given opportunities to do so" (1999, p. 454). Thus we must address the goal structure in the classroom; we must make attending to one another's ideas an important and valuable aspect of the activity. Engle and Conant address this with their design principle of holding students accountable to one another (2002). But, how do we achieve that goal?

3.1.3 Addressing the social and epistemic challenges by combining them

The epistemic and social challenges to argumentation are intricately connected. As discussed, the underlying rules of the classroom heavily influence the epistemic resources that are activated during discussions about science (Loucas et al., 2004; Smith, Maclin, Houghton, & Hennessey, 2000). If class discussions favor demonstration of the "right" answers over negotiation and knowledge-construction, then students have no reason to engage with the goal of persuasion. Moreover, they have no reason to use evidence—instead they simply must appeal to the authority of their teacher or textbook.

Given the relationships between these challenges, I conclude that we must address both challenges in order to resolve either (Hatano & Inagaki, 1991; Osborne et al., 2004). For example, in order to help students use evidence when constructing and evaluating knowledge claims, we must do more than tell students to use evidence, we must place students in a context that values evidence; we must support students in activating their epistemic resource for using evidence to make sense of experiences. Moreover, a lack of explicit criteria for evaluating classmates' explanations may be one reason students struggle with attending to one another's ideas through argumentative discourse; they may not know which criteria to use when evaluating these ideas. That is, addressing the epistemological challenges can provide students with the tools to engage the social challenges of argumentation. Finally, in order for students to engage with one another substantively, they must be in social situations that move beyond the typical goal of demonstrating acquisition of the teacher's knowledge and they must be in situations that demonstrate that scientific knowledge is worth debating—that it is more than a set of isolated facts. Thus, I conclude that fostering student participation in scientific argumentation requires addressing the social and epistemological challenges to this practice simultaneously. We must create situations that give students a reason to engage with one another and we must help them develop a language for doing so.

The following example taken from a pre-observation of one of the classes that participated in this study illustrates the complexity of this challenge. In this classroom, the teacher, Ms. W, designed an activity that attended to both the epistemic and social challenges to argumentation[10]. She asked her students to research different atoms and to prepare a presentation that would convince their classmates to "buy" their atom. On the day of the presentations, this teacher provided her students with a rubric to help them evaluate whether they would "buy" one another's atoms (see Figure 3.1). She also explicitly required her students to critique one another, calling on them to do so between each presentation. These strategies appear to address the above challenges: asking students to sell their atoms creates a goal that differs from the traditional goal of demonstrating expertise to the teacher; providing students with a rubric provides epistemic supports; and the requirement that students respond to one another directly addresses the social challenge that students typical do not do this.

[10] When teacher explained this project to me, she did not use this language, instead she discussed the students' task and goals. This analysis reflects my interpretation of the assignment.

ELEMENT	POINT DESCRIPTORS				
	4 *Exemplary*	3 *Proficient*	2 *Developing*	1 *Struggling*	0 *Incomplete*
INTRODUC-TION	The introduction clearly and coherently presents the overall topic and brings the audience into the presentation with compelling questions, visuals, or connecting to the audience's interests or goals.	The introduction presents the overall topic and brings the audience into the presentation by connecting to the audience's interests or goals	The introduction presents the overall topic and connects to what will follow.	The introduction has little structure and doesn't connect or give a clue to what will follow. It is overly detailed or incomplete.	No Introduction
CONTENT	The content gives evidence of good research. The presentation has a logical progression giving main ideas and supporting details. It is written clearly and concisely (not overly detailed).	The content gives evidence of research. The presentation has a logical progression giving main ideas and supporting details. It is written clearly.	The content gives some evidence of research. It is written clearly.	The content gives little evidence of research. It is overly detailed and logical progression is not evident.	No Presentation

Figure 3.1: Rubric Excerpt

Unfortunately, the students in this class did not engage in the argumentative aspects of this task. First, few of the presentations addressed the goal of "selling" an atom; rather than explaining the value of their atom, students generally provided factual PowerPoint ™ presentations, focusing on the number of neutrons, protons and electrons, in their respective elements. In addition, when called on to critique the presenters, students often had nothing to say. Moreover, when they did comment, their evaluations were focused on surface elements of the presentation and were directed at the teacher rather than the student presenting. For example, students would tell the teacher that they liked the font the presenter used. The teacher then evaluated whether the critiquing student had used the rubric to guide his or her evaluation. This teacher mediation and feedback meant that presenters were not asked to respond to the feedback thereby allowing them to ignore it. In this way, the critiques appeared to be an opportunity for students in the audience to demonstrate that they were listening, rather than an opportunity for the authors to improve.

Given that this project was framed in such a way as to consider both the epistemological and social challenges of argumentation, the students' lack of attentiveness to the argumentative aspects of this project were disappointing. By asking students to “sell” their atoms the teacher was giving the students a reason to pay attention to one another: they had to determine whether they were convinced that the atom was worth buying. In addition, by explicitly requiring that her students critique one another the teacher tied the students’ individual success to whether they evaluated one another thereby further attending to the social challenges of argumentation. Finally, she attending to the epistemological challenges of argumentation by providing the students with a rubric and creating a common criteria and language that students could use when evaluating one another. Unfortunately, even while Ms. W explicitly attended to the epistemological and social challenges of scientific argumentation, her students acted along the “unwritten rules” of typical classrooms: they presented facts while focusing on Ms. W and disregarding one another’s feedback (Lemke, 1990).

The challenges evident in this classroom reveal the paradigm shift we must make when attempting to foster student participation in scientific argumentation: we must do more than telling students it is time to argue (or, in this case, time to critique one another’s presentations). We must think of scientific argumentation as a *practice*. Practices hold the community together—they stem from a common set of beliefs and values and are perpetuated by social norms (Cole, 1999; Lave & Wenger, 1991; Wertsch, 1991). Using the lens of *practice* to understand argumentation in classrooms explains why simply telling the students to argue is an ineffective method for fostering argumentation: telling students to argue does not address the ways in which this new practice—scientific argumentation—aligns with and differs from the existing classroom norms (Cobb, 2002; Duschl, 2000; Hatano & Inagaki, 1991; Herrenkohl et al., 1999; Hogan & Corey, 2001; Osborne et al., 2004).

While the students were required to critique one another in the above example, the goals of the classroom had not changed. That is, the critiques were given to the teacher as a demonstration of the students' attention, rather than as feedback the presenters could use to improve their work. In order to motivate students to move beyond this more typical paradigm designers and teachers must change the classroom goals, creating situations in which engaging with one another is useful for the students' individual success. In this way, fostering argumentation entails more than telling students to talk to one another; it requires fostering new expectations for how the students and teachers will interact. To that end, learning environment designs must address the underlying goals and values in the classroom; students must find it valuable to attend to one another's ideas and evidence.

Further, there must be alignment between the criteria and the goal of the activity. In the above vignette, the students were asked to determine whether they would buy an atom. This goal does not require that the students attend to one another's evidence. Instead, this goal focuses them on the superficial elements: was the presentation entertaining? Do I think the atom is exciting? Is the atom useful? Given the alignment between the evaluative criteria and the questions, evaluation of evidence can only be motivated with questions that require its use. That is, curricular designs must address the social challenges of argumentation in ways that are consistent with the epistemological requirements.

As described, fostering scientific argumentation requires more than telling students to argue and giving them rules for how to do so. Moreover, the above example demonstrates that the challenges students face with scientific argumentation go beyond learning the skills of using evidence or critiquing one another. My design thesis is that addressing the social and epistemological challenges to argumentation requires the transformation of the interaction patterns of the classroom. That is, students must be in situations in which one another's ideas and the evidence supporting them are meaningful and valuable. This was the goal we took on in the curriculum on which this dissertation is based—the IQWST ecosystems unit. This unit accomplishes this by "creating a need" for students to take on the new practice of scientific argumentation. In the following sections I present the design strategies I developed with the IQWST biology team to meet this goal.

3.2 Design Strategies for Fostering Scientific Argumentation

In attempting to foster her students' engagement in the practice of scientific argumentation Ms. W asked her students a question that foregrounded the idea that they should convince each other; required that they evaluate one another's presentations; and gave them a rubric for doing so. Using the lens of practice, I would change this approach, slightly, using the following related design strategies for enabling and motivating students to take on norms consistent with the practice of scientific argumentation:

1. create a need for the students to use evidence when constructing and evaluating claims
2. create a need for students to attend to one another's claims and evidence, and
3. make the evaluation criteria explicit.

Before moving into the specifics of each of these strategies, I will take a moment to define this idea of "creating a need." It could be argued that the teacher in the above example addressed the second strategy by tying the students' grades to whether they offered their classmates' feedback. However, it did not work. As described above, these students did not engage with this activity in a way that was consistent with the practice of scientific argumentation. Instead, the norms of scientific argumentation were transformed to fit within the typical interaction patterns of the discussions that occurred in that classroom. This transformation is made evident when students in the audience offered their feedback to the teacher, rather than the presenter and when the teacher evaluated whether the feedback was relevant. In this way, the students and teacher were engaging in a traditional triadic dialogue, in which the content of the conversation was that of a presentation rather than science.

I hypothesize that this occurred because the need created by the teacher's assignment did not change the goal structure of the classroom. In this assignment, the students were evaluated on how they performed both when they presented and when they criticized one another, however the students' feedback was not a valuable part of the activity. The feedback was evaluated as "good" or "bad" by the teacher and ignored by the presenter. By not utilizing the students' feedback, the teacher did not create a need for her students to engage in the argumentative discourse; instead, she created a need for them to demonstrate that they were listening and could use her rubric. In the words of the "epistemic resources" perspective, this activity did not create a context that activated the students' resources for substantively evaluating one another.

The design goal of "create a need," refers to designing activities such that the context activates epistemic resources that align with the goals of scientific argumentation; such that the goal of the activity intrinsically necessitates the new practice. This strategy is similar to Edelson's (2001) design approach in which he focuses on motivating students to substantively engage in knowledge construction. His work suggests that the content students are learning must have a clear purpose, that one cannot expect students to deeply understand science concepts that serve no purpose. Thus, Edelson focuses on finding ways to make the science content useful to the learners. He focuses on “creating a need” for the content. For example, in curriculum Edelson has designed, students learn about the sun’s interaction with the atmosphere in order to construct policy recommendations on global climate change to send their senators (2006).

My approach to fostering argumentation is similar to Edelson’s except, rather than making the content useful, I focus on designing activities that enable students to experience the utility of the scientific practices—in this case, argumentation. For example, students must see the goal of persuasion as useful—as something that will fulfill a goal of the activity. Thus, Edelson’s designs create a “need to know” while my approach is focused more on creating a “need to do” (Kolodner et al., 2003).

This means that designers need to look at the questions that are asked, the process through which students go to answer the questions, the criteria they use to evaluate answers and the way the teacher evaluates them. Each of these aspects of the classroom activities must align with the new practice (in this case, scientific argumentation) such that students experience why the norms of the new practice are useful for meeting goals that are meaningful to them. This alignment between the new practice and the classroom activities is the crux of my design approach. Without this alignment, classroom communities will transform the new practice to fit the existing classroom norms, as they did in the above example, instead of vice versa. The following descriptions of these three design strategies make this idea more concrete.

3.2.1 Create a Need for Students to Use Evidence

As pointed out by DeVries, Lund and Baker (2002), in order for students to debate, the context must be rich enough to enable multiple perspectives. Moreover, the context must focus on the use of evidence to reconcile these multiple perspectives. As stated by Hatano and Inagaki "…constructive group interaction is often induced when group members talk about a set of clearly articulated alternatives that are falsifiable by empirical means" (p. 334). The literature on scientific argumentation in classrooms provides ample examples of problems that require students to make sense of evidence. For example, Blumenfeld et al. (1991) talk about students designing artifacts that require them to use complex thought to integrate multiple pieces of information. In the work by both Hatano and Inagaki (1991) and Osborne, Erduran and Simon (2004) we see the researchers presenting students with differing claims in which each claim is plausible, depending on their interpretation of the evidence. In each of these examples, researcher/designers create situations in which the students have a need to use data; the students are going beyond stating the data in order to apply it as evidence to solve the problem.

In the vignette above, the students presented facts (or data) about their atoms but the data was applied as evidence for neither solving a problem nor supporting a claim. That is, the question they were asked did not require that the facts be applied to solve a larger problem. Beyond affecting the presentations themselves, this narrow question focus also affected the audience members and their feedback. When determining whether to buy something, the surface features of the advertisement can distract individuals as they evaluate the item. To the extent that students engaged with the question of whether they would buy the atom, I believe that a similar phenomenon occurred here: the students were evaluating surface features of the presentation instead of the evidence because evidence was not necessary for them to engage with the question of whether they would "buy" the atom.

Consider how this interaction would have changed if the students were asked to choose between all of the presentations in order to identify an atom that they could live without. This framing of the question may have created a context in which the facts about the atom—the foods it is in and the functions it serves for humans—would have been necessary to construct and defend claims. At the conclusion of the presentations students could nominate atoms and use this data to defend their claims regarding why each atom was and was not necessary for human life.

3.2.2 Create a Need for Students to Argue

The practice-based perspective on scientific argumentation compels designers to go beyond asking the right questions. That is, while a rich question may create a need for students to use data when constructing their claims, it does not create a need for students to engage in the social aspects of argumentation; it does not create a context that values the students' ideas. As stated by Jimenez-Aleixandre "… learning environments designed to prompt argumentation should engage students in knowledge evaluation practices" (2008, p. 97). To do this, students must be accountable to more than just their teacher; they must be accountable to each other as well (Brown & Campione, 1996; Engle & Conant, 2002).

This design strategy goes beyond the typical classroom activity of asking students to critique or discuss one another's ideas, as the teacher in the above vignette did. As seen in that vignette, asking students to critique one another can result in students offering surface level criticisms without substantively engaging with one another's ideas. To avoid these results, designers have to find a way that student-to-student discussion is a natural part of their learning process. The peer discussion needs to have a value for the student such that attending to one another's ideas becomes valuable and meaningful to the students; peer-to-peer interactions need to have value for the student in order to activate epistemic resources that value peer ideas. Thus, we need to design situations such that students are motivated and empowered to engage with one another's ideas.

I have worked with the IQWST design team to design activities that accomplish this goal. There are currently two such activity structures in the curriculum:

1. Argument Jigsaw: Pairs of students construct an explanation. Two pairs then combine, compare explanations and converge on a single explanation on which all four students agree. This activity moves beyond telling students to evaluate one another's explanations by requiring them to reach consensus after they have constructed their initial ideas. By asking the students to construct preliminary arguments before joining the larger group students have an opportunity to develop ownership over their ideas thereby giving them an intrinsic reason to defend it, in the larger group. Then, by asking the students to join another pair and agree upon a single answer, we have asked the students to engage with one another's ideas so that they can determine how to combine their differing explanations. That is, in order to reach consensus, students need to compare their explanations, listen to one another as they defend and question each other and revise their final answer accordingly. In short, they need to argue. Thus, this activity structure goes beyond typical small group work by creating a need for students to engage with one another's ideas.

2. Whole Class Debate: The groups of four present their final explanations, with the ultimate goal of achieving a class consensus regarding the phenomenon under study. As with the Argument Jigsaw, the goal of consensus is used in order to activate student epistemic resources that value classmates' understandings in order to work through them.

These two activities work together in that the second, the Whole Class Debate, provides a forum for the product of the first, the Argument Jigsaw. Thus, during the Argument Jigsaw students are aware that the product of their work will be presented to and questioned by their classmates. In this way, the Whole Class Debate is designed to *create a need* for the product of the Argument Jigsaw. It is important to note that, as a stand-alone activity, the Whole Class Debate is largely equivalent to the atom presentations described in the above vignette. Thus, I clearly believe that the activity structure seen in the vignette has the potential to foster argumentation. The key difference between the Whole Class Debate described here and the presentations seen in the above vignette is that the goal of the Whole Class Debate is consensus building. It is hoped that this goal will motivate students to attend to one another's ideas in order to identify and reconcile differences.

3.2.3 Make the Epistemic Criteria Explicit

In order for individuals to engage in argumentation, they must have a common set of criteria that they use to evaluate one another. Without this shared criteria, arguers will be questioning and emphasizing different aspects of the argument (Cobb et al., 2001); they may not be attending to the same features (von Aufschnaiter, Erduran, Osborne, & Simon, 2008). Thus, beyond asking questions and creating social contexts that motivate and enable students to engage with one another's ideas, designers and teachers must help students develop shared criteria for evaluating one another's explanations.

The teacher in the atoms example accomplishes this by providing her students with a rubric. In this case, the rubric focused largely on superficial elements of the presentations including font size and color, PowerPoint slide layout and grammar. This rubric is consistent with the question the students were asked to evaluate. That is, if evaluating an advertisement these surface features are highly important. If the students' question changed to require the application of data (per the first design strategy), then the rubric would also have to change in order to support students as they began evaluating the alignment between one another's claims and evidence.

Other strategies for making the criteria of scientific argumentation explicit exist throughout the research literature. One strategy is to call out the components students must have in their arguments. For example, Osborne et al. (2004) supported students by giving them sentence stems that identified the components of a complete argument. The IQWST design work follows a similar approach, giving students an instructional framework that highlights the components of an argument, and discussing the criteria used to evaluate these components (Bruozas et al., 2004; McNeill et al., 2004).

It is important to recognize that these design strategies rely on one another: without activity structures that motivate argumentation, the explicit criteria becomes unnecessary because students have no need to evaluate one another. Similarly, without a shared criteria students may have difficulty engaging in the richer questions and activity structures because they may be using differing criteria. Finally, without a richer context the activity structures are unnecessary because the question will not motivate argumentation. In the following section I describe how the above design strategies were used in the IQWST ecosystems unit—the unit enacted for this study.

3.3 Application of Design Strategies in Study Curriculum

Three of the classes in this study enacted the same version of the IQWST ecosystems unit. The fourth class (Ms. B's class in 2005) enacted an earlier version of the unit. The designs for both versions of the unit were based on the above design strategies. Moreover, they had similar learning goals and activities. The pilot version of the ecosystems unit, the one used by Ms. B in 2005, is broken into two halves. The first focuses on learning goals surrounding the "characteristics of living things" and the relationship between an organism's structures and the functions it must perform in order to survive. The second half examines relationships between organisms (e.g., predator/prey, parasite/host) and competition for food or other resources.

Throughout the second half of the unit, students learn about these relationships in order to explain the impact of an invasive species, the sea lamprey, on the Great Lakes ecosystem.

The revised version was enacted by the remaining three classes and covered this same content with a slightly different organization. I present a detailed scope and sequence for both units in Appendices B and C, respectively. In the following sections, I describe specific ways that the design strategies discussed above are instantiated in the units.

3.3.1 Making the Epistemic Criteria Explicit in the Ecosystems Unit

Students are supported in the practice of scientific argumentation throughout this unit. First, the epistemic criteria for constructing and evaluating arguments are introduced through the "evidence-based scientific explanation" instructional framework (McNeill et al., 2006), that students use. These "scientific explanations" could be viewed as an argumentative product; they are the students' recordings of their final arguments. Students are introduced to this framework in Lesson 3 of the unit enacted for this study. They then construct and evaluate these scientific explanations throughout the unit. Moreover, teachers were asked to make explicit connections between these written scientific explanations and the argumentative discourse that occurs when students negotiate their understandings. In these discussions, students were asked to identify and evaluate their claims and justifications, in order to reach a class consensus regarding the scientific knowledge under study. As such, this framework highlighted the epistemic criteria for evaluating arguments and became a tool for students to use when engaging in scientific argumentation.

As found by Quintana et al. (2004) this approach of supporting students' sensemaking by providing tools students can use to articulate their explanations in a way that is consistent with the norms of the scientific community is a common strategy in the design of learning environments. For example, Suthers, Toth and Weiner (1997) designed and investigated a software-learning environment, Belvedere, to support students in distinguishing between evidence, prior knowledge, theories, and the connections between them. The software does this by making these types of knowledge explicit in the representation of the students' explanations. When working in this environment, students record and connect the evidence they collect with the hypotheses they generate. This software was designed to influence the students' sensemaking process by structuring the ways in which students articulate their understandings. Sandoval and Reiser (2004) also designed software to help students learn the ways in which scientific knowledge is constructed and defended. Their system is designed to highlight the relationship between explanations and evidence. That is, similar to the Toth et al. software, this learning environment structured the students' articulation in order to influence their sensemaking process.

The IQWST instructional framework team drew on Toulmin's (1958) argumentation model to make explicit the importance of justification when communicating scientific explanations. This framework contains three components:

- *Claim*: the answer to the question
- *Evidence*: information or data that supports the claim
- *Reasoning*: a justification that shows why the data count as evidence to support the claim

Detailed description of the components in this framework can be found in McNeill et al.'s (2006) study.

3.3.2 Creating a Need for Students to Use Evidence in the Ecosystems Unit

The instructional framework discussed above highlights the importance of evidence. However, as a stand-alone scaffold, this does little more than *tell* students to use evidence; the instructional framework does not create a need for students to use evidence. When designing the Ecosystems Unit, the IQWST team addressed this by identifying questions for which there were multiple claims that could be reconciled with evidence, and by providing students with the data necessary to do so. For example, in Lesson 3, students are asked to construct scientific explanations regarding whether microscopic things that they observed were living things (as opposed to objects that never lived). In order to answer this question, students had to synthesize their observations of the microscopic things. Designers expected this question to elicit debate because different students would make different observations depending on their sample. Moreover, different students would define “living” differently. For example, the two classes that enacted this lesson had a discussion about whether they had observed the microscopic things moving and whether movement counted as evidence that it was a living thing.

Lesson 8 is an additional example of a lesson designed around a question that elicits students’ use of data to reconcile opposing claims. In this lesson students were presented with evidence from an experiment about plant growth. This experiment examined the growth of plants with and without the resources of soil, water and sunlight. Students were asked to use this evidence to determine whether plants need soil to live. As designers, we predicted that this question could inspire student argumentation because students typically have different ideas regarding whether plants need soil and the evidence was designed to demonstrate that plants do not need soil.

In addition to these lessons, three other lessons were designed to use Argument Jigsaw and Whole Class Debate to reconcile questions explicitly selected to foreground the importance of evidence when making sense of phenomenon. Due to enactment complications, one of the classes in this study enacted one of these lessons, one class enacted two and one enacted all three. The fourth class (Ms. W) did not reach any of the lessons that used this design strategy. The one lesson that three of the classes enacted is a focus of my analyses and I provide details about that lesson in the following section.

3.3.3 Creating a Need for Students to Argue in the Ecosystems Unit

The Argument Jigsaw and Whole Class Debate activity structure pair was used in three different lessons in this unit. As discussed above, this activity structure was designed to create a need for students to use evidence and argue with one another. That is, this activity structure was designed to create a social context and goal structure that motivated students to attend to, evaluate and critique their classmates' ideas, using evidence.

The lesson most frequently enacted in this study that utilizes this activity structure pairing (i.e., Argument Jigsaw and Whole Class Debate) was the "Invasive Species" lesson. The purpose of the lesson was for students to explore interactions between organisms in a food web, with particular emphases on the idea of competition for resources. Students did this by working with a computer model of a miniature ecosystem (using the NetLogo environment, Wilensky, 1999). In the beginning of the students' work with this simulated ecosystem, it contained three organisms: foxes, rabbits and grass. These organisms exist in a simple food chain: the foxes eat the rabbits and the rabbits eat the grass. In this system, changes to one population affect another. For example, if the rabbit population increases the fox population is able increase because it has more food. A higher fox population causes the rabbits to decrease because they have more predators. Reduced rabbits cause the fox population to decline, thereby allowing the rabbits to increase again. This cycle continues in a stable manner, indefinitely. A similar cycle is evident between the grass and rabbits. Figure 3.2 depicts these cyclical relationships.

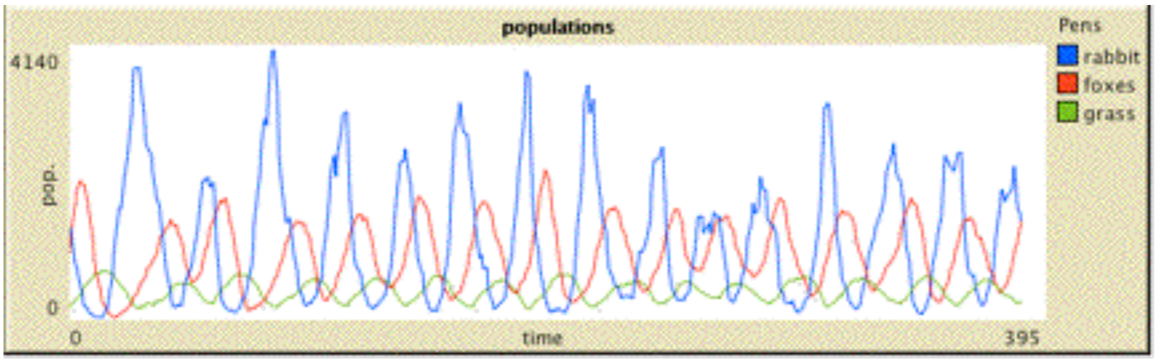

Figure 3.2: Example Graph of Population Fluctuations in the NetLogo Simulation

Once the student-pairs were able to identify variable values that result in these stable relationships, and explain these population fluctuations, they introduced an unknown organism into their mini-ecosystem. They then examined the new population fluctuations in order to identify what the “invasive species” eats.

The students’ explorations resulted in a complex data set that supports multiple plausible claims. For example, the rabbit population frequently dies out when the invaders enter. Beyond the rabbit population changes, introduction of the invasive species also correlates with a grass decline and fox population fluctuations. There are two probable claims that could explain these results: the invader could be eating the rabbits or competing with the rabbit population for grass.

Students work with this simulated ecosystem for about a week. This begins with about two days of partner work in which students become familiar with the software environment and the cyclical relationships between the organisms in the ecosystem, and develop initial arguments regarding the food of the invasive species. The student-pairs then engage in an Argument Jigsaw by joining another pair and forming a group of four. For the next one to two days, the students in the Argument Jigsaw groups argue with one another and gather additional evidence from the ecosystem in order to reach consensus regarding the invasive species' food. This activity structure "creates a need" for students to argue by making the explicit goal of the activity one of consensus building which can only be accomplished when students attend and respond to one another's claims and evidence.

Once the activity jigsaw groups have reached consensus, the class reconvenes to engage in a Whole Class Debate in which the goal is to determine, as a class, what the invader eats. Classes structured this debate in different ways, ranging from students debating interpretations of a NetLogo graph to student groups formally presenting their arguments. At the conclusion of the Whole Class Debates the teachers each facilitated the consensus building by leading a "wrap-up" discussion in which the teacher took a more active role. I describe details of the class enactments of this lesson in Chapter 4.

3.4 SUMMARY

The design principle presented here is based on the assumption that traditional classroom norms can inhibit student participation in the practice of scientific argumentation. Given this assumption, fostering scientific argumentation requires creating opportunities for the students and teachers to transform their the interaction patterns found in their class' discussions such that they more closely align with those of the new practice. At the crux of this approach is the idea that the context must *create a need* for these ways of interacting. That is, the norms of the new practice must make sense in the context of the classroom. For example, the goals of traditional classrooms encourage students to demonstrate individual mastery over the teacher's knowledge. This neither necessitates nor motivates students to engage with one another's ideas. Thus, in order to foster argumentation, we must create a need for students to go beyond this demonstration of knowledge in order to attend to one another's claims and evidence.

Based on this principle, I developed three design strategies to support students and teachers as they transform their classroom practices to more closely align with scientific argumentation. First, create a need for students to go beyond the recitation of data; they must apply it as evidence to solve a problem. Second, create a need for students to engage with one another's ideas in argumentative discourse. Finally, support these conversations by helping students develop explicit epistemological criteria for constructing and evaluating scientific arguments.

I concluded this chapter by describing the activities and questions that the IQWST design team and I used to instantiate these strategies. In Chapter 4, I explore the ways in which the different classrooms enacted these activities in order to characterize the ways in which classroom communities transform the practice of scientific argumentation to make it meaningful. In Chapter 5, I extend this analysis in order to understand why each classroom community adapted the argumentative practice in the ways that they did.

Chapter 4: Classroom adaptations of scientific argumentation

The two conjectures that this dissertation explores—that the students' argumentative discourse will reflect a combination of the existing classroom practices and the norms of the practice and that there are many different forms of argumentative discourse—lead to two research questions. First, if students' engagement in scientific argumentation will differ from that of the scientific practice, then we need to characterize the ways in which students take up this practice. Thus, my first question is: How do classroom communities transform the practice of scientific argumentation? Second, if the students' engagement in argumentation depends on typical ways of interacting in each class, then understanding variation in how the classes engage in this practice requires understanding the existing cultures in each classroom. In other words, my second research question investigates why classrooms adapt the argumentative practice in the ways that they do by examining both the typical classroom interactions and the immediate learning environment. I address this second question in Chapter 5, in which I focus on the relationship between the classroom communities' adoption and adaptation of scientific argumentation and their existing classroom culture. This chapter focuses on the first question: How do different classrooms transform the practice of scientific argumentation to make it meaningful in their context?

As such, this chapter provides the foundation upon which the rest of my dissertation will rest; this chapter elucidates the various ways in which middle school classrooms engage in and make sense of the aspects of scientific argumentation. In the following chapter, I move on to characterize the existing cultures in each classroom community in order to explain how these existing ways of interacting influence the class' adoption and adaptation of scientific argumentation. Through this work, I begin to understand why each class' adaptation of the practice was meaningful in that context – why the practice was adapted in the ways that it was.

4.1 Analytical Approach

I explore the ways in which the classrooms adopted and adapted the *persuasive, sensemaking* and *articulating* goals of scientific argumentation by describing variation in the discourse patterns of classroom discussions designed to facilitate student engagement in this practice. I use discourse as an indicator of student engagement in scientific argumentation for two reasons. First, argumentation is, by its very nature, a discursive activity. Consequently examining the discourse that occurs means that I am examining the argumentation that occurs. Secondly, while self-reports through interviews and surveys can provide insight into what participants think they were doing, I am more interested in what they were actually doing. That is, my analysis was designed to capture the ways in which students engaged in the practice more than the ways in which students talk about it. However, using classroom discourse to characterize student attention to each of the goals of scientific argumentation poses a challenge: how does one determine whether a particular discourse event is related to argumentation and, if it is, how that event is related to the goals of argumentation?

Figure 4.1 reviews the framework presented in Chapter 1. This framework is my proposed solution to this challenge: it shaped my coding scheme (presented in Chapter 2) and guides my analytical approach.

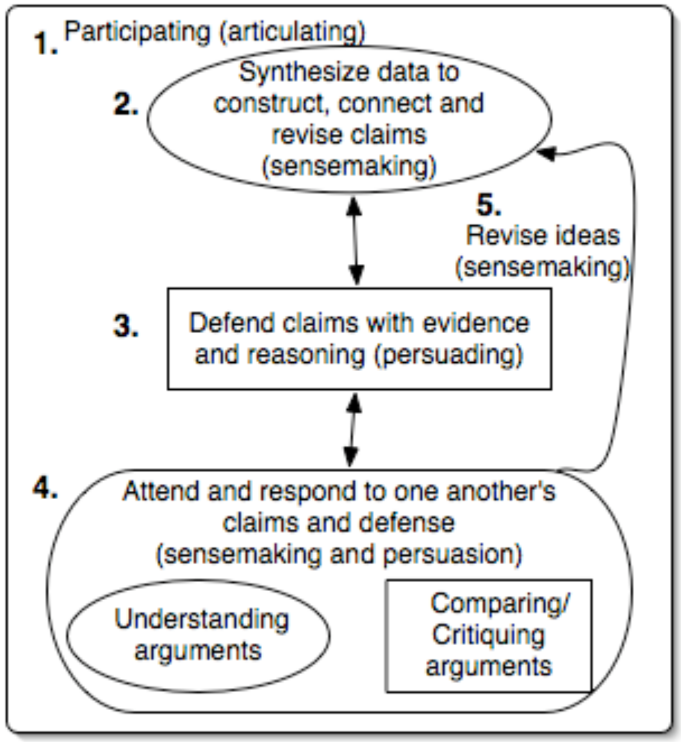

Figure 4.1: Discourse characteristics of scientific argumentation

I use the characteristics of argumentative discourse presented in Figure 4.1 to examine the ways that classroom communities adapt the practice of argumentation. In particular, I examine what students say and the context in which they make these contributions in order to examine the ways in which their discourse did and did not reflect the instructional goals of argumentation. For example, in the following analyses I demonstrate that Mr. S's students engaged in persuasion by both defending their claims and responding to one another's ideas. In contrast, the discourse in which Ms. B's 2006 students engaged reflected a different version of persuasion: these students defended their claims but attended to one another's ideas only minimally.

Table 4.1 summarizes how I use the coding scheme to indicate whether each discourse characteristic is present in the students' discourse and how those characteristics relate to student attention to the goals of argumentation.

Table 4.1: Summarizing the ways in which the coding scheme indicates discourse characteristics that demonstrate attention to each of the instructional goals of scientific argumentation

Instructional Goal	Discourse Characteristic	Indicators in the discourse	Coding step that reveals this
Articulation	Aspect 1: Participation	Students making argumentative contributions.	Step 2: Code for utterance functions
Persuasion	Aspect 3: Defense of ideas	Students justifying their ideas.	Step 3: Examine justification patterns
	Aspect 4: Attention to one another's ideas	Students responding directly to one another's ideas as much or more than they respond to a teacher prompt.	Step 4: Examine interaction patterns
Sensemaking	Aspect 2: Constructing and connecting claims	Students contributing claims.	Step 2: Code for utterance functions
	Aspect 4: Attention to one another's ideas	Students responding directly to one another's ideas as much or more than they respond to a teacher prompt.	Step 4: Examine interaction patterns
	Aspect 5: Revision	Students revising their ideas in light of a challenge.	Step 5: Examine the conclusion of the challenging episodes

This table belies the complexity of this analysis. For example, this table indicates that if students justify their ideas, then their discourse will indicate that they are attending to that aspect of persuasion. This raises the question: How frequently do they have to justify their ideas for this to be true? However, as stated by Loucas and Hammer when using similar coding schemes to analyze classroom discourse: "…there is not a theoretical basis that warrants committing to any of the existing schemes as defining what constitutes greater or lesser sophistication in argumentation" (in review, p. 27). In other words, each of these indicators requires a rule for determining whether it is present.

As there are no empirical or theoretical measures of how much each of these codes must appear in order to demonstrate that the discourse reflects these characteristics, I use cross class comparisons and relative frequencies. For example, in order to determine whether students are defending their ideas, I compare the frequency of student-justified-ideas to the frequency of student-unjustified-ideas. This comparison illustrates which discourse characteristic is more emphasized in each class. Moreover, this type of analysis does not require a cross-class comparison because it achieves the goal of elucidating how students engaged in the goals of argumentation without it.

In some instances, I add a cross-class comparison to the within-class analyses in order to help interpret the results of the discourse analysis. For example, in Section 4.4, I will demonstrate that Ms. B's 2005 students were equally likely to evaluate one another's ideas as they were to question them. As a unique data point these relative frequencies are not very informative. However, comparing this class to Mr. S and Ms B's 2006 classes in which students evaluated one another about twice as often as they questioned reveals that Ms. B's 2005 students were, in fact, emphasizing questioning. This interpretation informs the profile I create of Ms. B's 2005 students: as will be shown, I concluded that her students were more interested in understanding one another's arguments than were either Mr. S' or Ms. B's 2006 students.

In instances in which the cross-class comparisons informed the conclusions I drew, I conducted non-parametric statistical tests in order to determine whether the apparent differences were reliable.[11] However, the bulk of my analysis does not rely on statistical comparisons. Instead, my analyses examine the emphases within a single class and quickly move beyond the numerical comparisons to examine how these emphases are apparent in and impact the student discourse.

In the following sections I explain how I use patterns in the student discourse to indicate whether and how student discourse reflects each of the goals of argumentation. I also present tables summarizing the cross-class comparisons for each of the key variables being discussed. These tables serve to prepare readers for the detailed discussions of each individual class that follow.

4.1.1 Discourse indicators of articulating

We (Berland & Reiser, in press) recently assessed student engagement with the articulation of arguments by considering the clarity their written arguments. That is, we examined the degree to which students articulated clear arguments. However, when moving from written to spoken dialogue the goal of articulation shifts the focus from *verbal* articulations. Thus, I must expand my indicators of articulation in order to account for the verbal discourse.

As discussed in Chapter 1, students must articulate in order to persuade one another and to engage in argumentative sensemaking. Thus, this goal of argumentative discourse conceptually overlaps with the others. I minimize this overlap in my analyses by narrowing my definition of articulation to emphasize the degree to which students verbally contributed to the

[11] I used the non-parametric tests because the sample size was too small to warrant parametric measures

argumentative discourse in substantive ways. With this emphasis, I am examining the degree to which students' contributions fulfilled argumentative functions (as defined in Chapter 2, including making claims, justifying, questioning etc.) and I am thereby examining the degree to which students were articulating parts of an argument. That is, the frequency with which students contribute argumentative utterances is an indicator of their engagement in articulation. This is a relatively simple indicator of engagement in *articulation*, in that it only examines one variable; I am essentially looking at the degree to which students articulated arguments without unpacking this articulation to examine what they were articulating (i.e., this analysis does not assess whether students stated justifications and asked questions) or why they made those articulations (i.e., whether they only justified in response to a teacher prompt). This unpacking is left for later analyses in which I use the content and context of student utterances to examine how they engaged in persuading and sensemaking.

In analyzing the frequency with which students' contributions performed argumentative functions, I am going beyond examining student participation, generally, in order to focus on when their contributions are taken up in an argumentative manner. In order to clarify this measure I return to the distinction, first made in Chapter 2, between argumentative and non-argumentative contributions that are both content rich.

Transcript 4.1 presents a content-rich exchange in which the ideas were handled in a non-argumentative manner; the ideas were offered as facts that the teacher could assess as right or wrong and students did not question those teacher evaluations. This exchange comes at the end of the discussion regarding what plants need to survive when Ms. W was attempting to help students connect the current discussion to the idea of photosynthesis. She wanted students to realize that it makes sense that plants can grow without soil because photosynthesis does not require it.

1	Teacher	What has to go into the plant so it can do photosynthesis?	Non-argumentative
2	Teacher	Christina?	Non-argumentative
3	Christina	I can't pronounce this..carbo-hy-something	Non-argumentative
4	Teacher	Okay, you're right, it has to have carbon dioxide. Which is a gas in our atmosphere.	Non-argumentative

Transcript 4.1 Non-argumentative exchange in Ms. W's class

I have coded each line of the exchange presented in Transcript 4.1 as non-argumentative because no utterance presents the ideas of something that could be questioned and/or debated. Instead, the teacher asked a question for which she expected and would accept a single answer, Christina answered that question and the teacher evaluated her response. This is a typical IRE or triadic dialogue (Lemke, 1990; Mehan, 1979) exchange, as described in Chapters 1 and 3.

When analyzing the degree to which students engaged in articulating arguments, exchanges such as the one shown in Transcript 4.1—in which knowledge is treated as facts to be learned rather than concepts to be questioned—were not counted. In contrast, Transcript 4.2 presents an example of a teacher-led exchange in which the ideas were being discussed as if they were questionable. In this exchange, the class was examining a table of data that describes seedlings as they grow in different conditions (e.g., some have access to soil, others don't). Prior to the exchange presented in Transcript 4.2, the class had concluded that, based on the evidence, plants need water to grow (those that did not have access to water were dying).

1	Teacher	So what about soil, do we have to have soil?	Questioning
2	Students	No	Claiming
3	Students	Yes	Claiming
4	Teacher	Kevin	Non-argumentative
5	Kevin	I think so	Claiming

6	Teacher	Based on evidence, assuming that this was good data, and we'll make that assumption.	Criteria
7	Teacher	Based on the evidence what do you need?	Questioning
8	Kevin	I would say, based on evidence its better. I said it is both. [can grow plants w/ or w/o soil]	Claiming
9	Kevin	No [plants do not need soil] because it is like 5 to 2. [Group] 5 [that did not have soil] is [grew] 5 cm and 6 group [that also did not have soil] is [grew] 2 cm.	Justifying

Transcript 4.2: Argumentative exchange in Ms. W's class

One might have expected this transcript to reveal a simple IRE exchange, as did Transcript 4.1, because there was one right answer in each exchange (plants do not need soil). However, I have coded these utterances as performing argumentative functions because, rather than simply evaluating the students' answers, the students and teacher questioned, challenged and revised one another's ideas. In other words, the ideas being discussed were presented as something that could be debated and questioned.

For example, the argument began in Lines 2 and 3 in which students made contradictory claims regarding whether plants require soil to grow. This contradiction immediately identifies the students' claims as something that might be questioned. Then, rather than resolving the dispute and moving on, Ms. W asked one student to justify his claim that plants need soil to grow (Lines 6 and 7). In response to this prompt, Kevin revised his claim: in Line 5 he claimed that plants need soil to grow while in Line 8 he claimed that plants do not always need soil to grow. He then justified this claim using evidence from the data table (Line 9).

To assess the degree to which the students' discourse provided evidence of their attention to the goal of articulation, I examined the frequency with which their utterances fulfilled an argumentative function—such as the exchange seen in Transcript 4.2—by treating knowledge as something that could be questioned and debated. In particular, I compared the relative frequencies that students made argumentative contributions in each class in order to identify differences in degree of students articulating. Table 4.2 summarizes this comparison.

Table 4.2: Average number of argumentative utterances students contributed during the argumentative discussions in each class

Class	**Average number of argumentative utterances**
Ms. B, 2006	9.3 per three-minute interval
Mr. S	14.3 per three-minute interval
Ms. B, 2005	19.4 per three-minute interval
Ms. W	8.6 per three-minute interval

Table 4.2 reveals that the students contributed argumentative utterances at different rates in the four participating classes. I interpret these differences throughout this chapter, here I use the table to highlight them: Two of the classes (Mr. S and Ms. B, 2005) show relatively high rates of student participation while students in the other two participating classes (Ms. B, 2006 and Ms. W) made argumentative contributions at lower rates.

4.1.2 Discourse indicators of persuading

One indicator of engagement in persuasion is the defense of ideas. This is the indicator used in Berland and Reiser (in press) and it aligns with science education literature that evaluates the quality of student arguments in terms of whether and how claims are defended (as reviewed in Sampson & Clark, in press). Moving beyond this product focus in order to examine the discourse of argumentation makes it possible to examine student persuasion in other ways. In particular, as seen in Figure 4.1, attending to one another's ideas—determining whether one is persuaded by the arguments of others—is another way individuals can engage with the goal of persuasion. I analyze both of these aspects of the student discourse in order to determine whether and how student discourse reflects attention to the goal of persuasion.

In order to determine whether the students are defending their ideas I focus on the relative frequency to which students take positions that could be defended and justify those claims. This aligns with a previous study I conducted with Reiser (Berland and Reiser, 2008) (discussed in Chapters 1 and 3), in which we examined the degree to which students engaged with persuasion by analyzing whether their claims were clearly justified in their written arguments. I extend my analytical approach for written work to the verbal interactions by focusing on the justification patterns in the students' discourse, rather than examining the justifications found in their written arguments. As discussed in Chapter 3, the justification patterns combine student utterances in order to differentiate between those ideas that are justified and those ideas that are not justified. When examining the justification-patterns I identified those utterances in which an idea was presented as something new that could be defended (by either contradicting an already stated idea or by defending this idea). As such, an evaluative statement, question or claim could each present a new idea, and are each an opportunity for students to state and stand for a new idea. After identifying those utterances in which a participant identified and stood by an idea, I determined whether that idea was justified in the discussion. Through this analysis, I differentiated between ideas that were and were not justified, regardless of whether the same student stated and justified the idea. Table 4.3 summarizes the results of this analysis.

Table 4.3: Percentage of ideas students justified in each class

Class	**% of justified ideas**

Ms. B, 2006	63% (5 of 8)
Mr. S	65% (24 of 37)
Ms. B, 2005	65% (11 of 17)
Ms. W	58% (23 of 40)

As seen in Table 4.3, students in all four classes justified their ideas at similar rates (χ^2(2, n = 102) = .5, and p > 0.4). As will be discussed throughout this chapter, this similarity indicates that students in all of the classes engaged in this aspect of argumentative discourse to the same degree.

I examine whether and how students attend and respond to one another's ideas by first examining the interaction patterns in the discussions. The interaction codes highlight patterns in who makes contributions and why those contributions are made. For example, they elucidate whether a student contribution was in response to a classmate's utterance or a teacher prompt. In this analysis, I use these interaction patterns to examine whether students are responding to one another's ideas—I therefore focus on the different relative frequencies with which student contributions are made in response to a classmate's or teacher's utterance. Table 4.4 summarizes the results of this analysis.

Table 4.4: How student contributions were elicited

Class	**% of interactions in which students respond to students**	**% of interactions in which students respond to teacher**
Ms. B, 2006	38% (13 out of 34)	38% (13 out of 34)
Mr. S	71% (69 out of 97)	12% (12 out of 97)
Ms. B, 2005	82% (63 out of 77)	7% (5 out of 77)
Ms. W	18% (15 out of 84)	51% (43 out of 84)

Using a chi-square test to examine the differences shown in Table 4.4 reveals that Mr. S and Ms. B's 2005 respective classes responded to one another's ideas at statistically similar rates ($\chi^2(1, n = 174) = 2.03$, and $p > 0.1$) and that students in both of these classes responded to one another's ideas significantly more than did students in the other class that participated in the Invasive Species Whole Class Debate—Ms. B's 2006 class ($\chi^2(2, n = 208) = 24.7$, and $p < 0.01$). As will be discussed at more length, this indicates that students in Ms. B's 2006 class reacted to the Invasive Species Whole Class Debate differently then students in the other two classes that enacted it did.

Once the interaction pattern has elucidated whether students are substantively responding to one another's ideas, I turn to the functional analyses of the students' utterances to examine the substance of those interactions. The utterance level codes break participants' contributions into coherent pieces in order to identify the functions performed by a single turn of talk. This approach aligns with other science education literature (Clark & Sampson, 2007; Erduran et al., 2004) focused on understanding whether and how scientific arguments that occur in classrooms fulfill the structural expectations of argumentative discourse (Toulmin, 1958). These functional codes makes distinctions such as whether students are responding to the ideas discussed by stating their own ideas (making a claim), evaluating an idea on the table or questioning the ideas discussed. Thus, I use this analysis to understand how students are responding to the ideas being discussed. Table 4.5 presents this analysis.

Table 4.5: Percentage of utterances that were questions and evaluations[12]

[12] These percentages do not add up to 100% because I am showing only those functions that appear in the later analyses.

Class	Questioning	Evaluating
Ms. B, 2006	7% (12 of 56 utterances)	21% (4 of 56 utterances)
Mr. S	9% (37 of 172 utterances)	22% (15 of 172 utterances)
Ms. B, 2005	18% (22 of 155 utterances)	14% (28 of 155 utterances)
Ms. W	6% (7 out of 118)	14% (17 out of 118)

The classes differently emphasized evaluating and questioning ($\chi^2(2, n = 127) = 9.5$, and $p < 0.01$).[13] Examining Table 4.5 suggests that Ms. B's 2005 students appear to place more emphasis on questioning than do Mr. S' and Ms. W's students; Mr. S' and Ms. W's respective students were twice as likely to evaluate one another's ideas as they were to question them, while Ms. B's 2005 students questioned and evaluated at equivalent rates.

4.1.3 Discourse indicators of sensemaking

In Chapter 3 and Reiser and Berland (in press), I looked for evidence of sensemaking in the students' written arguments by examining whether the students were positing claims that were consistent with the available evidence. However, moving to verbal argumentation creates new ways that students can demonstrate and engage in sensemaking. My analyses identify three discourse characteristics that can illustrate student attention to the goal of sensemaking. Based on Figure 4.1, these aspects are: constructing and connecting an initial claim (aspect 2); attending and responding to classmates' ideas (aspect 4); and revising their original claims in order to account for the contradictory ideas and evidence discussed (aspect 5). Individually each of these discourse characteristics indicate a form of sensemaking. I combine them in my analyses to generate a profile of all the ways that each class engaged in this goal. For example, I found that Ms. B's 2006 class engaged in sensemaking by constructing their initial claims but did not

[13] I do not include Ms. B's 2006 class in this comparison because they made only 56 argumentative utterances during their Whole Class Debate making statistical analyses unreliable.

substantively respond to one another's ideas or revise their own. In this section I describe how the coding scheme described in Chapter 2 identifies these aspects of the classroom discourse.

In these analyses I assume that students have constructed their initial claims. This assumption is based on the fact that students in all of the classes contributed claims relatively frequently. To contribute the claims the students must have been constructing them. Attention and response to one another's ideas is assessed using the same scheme discussed in Section 4.1.2: examining the frequency with which students respond to one another's ideas and the function of their utterances when they do so (shown in Tables 4.4 and 4.5).

I use the analysis of the Challenging Episodes to explore the degree to which students in each class engaged in final aspect of argumentative discourse: revising their ideas in light of one another's arguments. As defined in Chapter 2, episodes are the largest grain-size of the classroom interactions that I systematically coded. They are combinations of interactions in which the participants, content and interactions are all similar. Examples of episodes include: students presenting arguments, teacher questioning dialogues and Challenging Episodes. I focus on the Challenging Episodes in this analysis—those episodes in which one individual challenges the ideas of another by explicitly contradicting it, offering evidence that calls the claim into question or simply questioning it. I predict that these episodes would be fruitful places to look for students' engagement in synthesis of competing arguments because they are the instances in which student ideas are explicitly placed in contradiction with one another. Thus, I examine the way in which students concluded these Challenging Episodes—resolved their different arguments—in order to gain insight into how they engaged in sensemaking. Table 4.6 presents the conclusion of this analysis.

Table 4.6: Conclusion of challenging episodes in each class

Class	Acknowledge	Neutral Answer	No resolution	Revision	Teacher resolves	Total
Ms. B, 2006	0	2	1	0	0	3
Mr. S	2	3	13	2	0	20
Ms. B, 2005	1	13	4	0	1	19
Ms. W	4	0	3	5	0	12

As seen in Table 4.6, each of the classes concluded their challenging episodes in different ways: Ms. W's students were the only ones to revise their ideas with any frequency while Ms. B's two classes both emphasized a neutral answering of the challenges without acknowledging disagreements. This finding is discussed at more length throughout this chapter.

I use these comparisons and analyses of the classroom discourse to explore the ways in which each classroom community adopted and adapted the practice of scientific argumentation. That is, I use the discourse patterns elucidated through the analytical approach outlined in this section to characterize each class' argumentative discourse in terms of whether and how they engaged in each of the instructional goals of argumentation. In addition, I use these discourse patterns to identify which of Walton's (1998) dialogue types the classrooms argumentative discourse most closely resembles. This attribution provides insight into the purpose of the argumentative discourse—as seen by the students.

4.1.4 Argument Context

I analyze the classroom discourse that occurs in four classes as they enact lessons designed to facilitate student engagement in scientific argumentation. The bulk of this analysis focuses on the Invasive Species lesson, in which three of the four classes engaged. Table 4.7

shows the total number of minutes of argumentative discussions that were analyzed for each class. The variability across the first three classes (Ms. B's two classes and Mr. S' class) stems from differences in their enactments of the Invasive Species Whole Class Debate. Ms. W's class has more minutes of argumentative discussions analyzed because I was able to include two discussions instead of just one.

Table 4.7: Minutes of argumentative discussion analyzed for each class

Class	**Minutes of argumentative discussion analyzed**
Ms. B, 2006	18 minutes
Mr. S	36 minutes
Ms. B, 2005	24 minutes
Ms. W	69 minutes

I described the Invasive Species Whole Class Debate in which three of the four classes participated in Chapter 3; I briefly review the lesson sequence here. In this lesson, students explore a computer-simulated ecosystem that contains foxes, rabbits and grass. Students introduce an unknown organism – an invasive species – to this ecosystem and examine the population fluctuations that ensue in order to identify this organism's food. This week long lesson involves four activities:

1. Initial exploration: students work in pairs to determine what the invader eats and evidence to support those claims
2. Argument Jigsaw: pairs combine to form groups of four that are responsible for constructing a single argument with which all four students can agree
3. Whole Class Debate: groups present and discuss their different arguments for the invader's food.

4. Wrap-up: Teacher facilitates a discussion in which students reach consensus regarding the invader's food.

My analyses in this chapter focus on the discussion that occurred during the Whole Class Debate. I chose this activity over the Argument Jigsaw because the majority of this small group work took place in front of the computer and the discussion that ensued consisted of incomplete references to the computer. That is, the lack of structure in the small group discussions made it almost impossible to identify the argumentative function of most of the student utterances. I chose the Whole Class Debate over the Wrap-up discussion because I was wary of the teacher's influence; my research is focused on understanding the ways that the classroom community adopted and adapted the practice of scientific argumentation and while the teacher is part of that community, an analysis of teacher-led discussions may over-emphasize the teacher's understanding and under-emphasize the students' understanding.

As discussed in Chapter 3, the IQWST unit had three lessons that used the above sequence of activity structures around different data sets and content. I focus on the NetLogo lesson because three of the classes in my study engaged in this lesson. No other lesson had this much participation. Using the same lesson across cases allows me to account for differences in how the classes take up the practice of scientific argumentation in terms of the differences in existing classroom cultures rather than specifics of the activity design and/or content.

In the following sections, I characterize the ways in which students in each class articulated, persuaded and made sense. I organize this analysis around each of the individual classes. However, as it is difficult to ascertain what is "normal" each analysis is enhanced by referring to the data tables presented in Section 4.1 in order to identify those characteristics that are unique to the class currently in focus. This analysis is used in future chapters in which I explore why different classes engaged in these practices differently. I begin by examining Ms. B's 2006 6th grade class using the analytical approach described in Section 4.1 in order to characterize the ways in which students in this class engaged in the articulation, persuasion and sensemaking goals of scientific argumentation.

4.2 Ms. B, 2006

I characterize the ways in which students in Ms. B's 2006 class adopted and adapted the practice of scientific argumentation by first providing an overall description of the Invasive Species Whole Class Debate that occurred in this classroom. I provide a more detailed analysis of this discussion by characterizing student engagement in each of the three goals of scientific argumentation, individually. In Sections 4.3, 4.4 and 4.5, I use analyses of other classes; Mr. S, Ms. B's 2006, and Ms. W's classes, respectively; to explore the breadth of ways in which students adopt and adapt the practice of scientific argumentation.

The Invasive Species Whole Class Debate that occurred in Ms. B's 2006 class illustrates a typical classroom presentation sequence in which student groups presented their ideas and listened to other groups' presentation with little interaction between groups (Lemke, 1990). This Whole Class Debate had a clearly defined activity structure: student groups rotated through presentations while the rest of the class observed. Throughout the Whole Class Debate, student groups stood at the front of the room reading from arguments they wrote during the small group work. Two of the four groups in this class did not reach consensus within their groups. Instead, when they presented, the teacher allowed individuals within each group to present opposing arguments. At the conclusion of each presentation, Ms. B asked whether the observing-students had any questions for the presenting group. The excerpt shown in Transcript 4.3 exemplifies the interactions observed in this Whole Class Debate. In this exchange, Alisha, Bobbie, Krissy and Lakisha presented their argument that the invader ate grass.

1	Alisha	Um, we said that the invader eats grass because…	Claiming
2	Student	[applauds]	Evaluating
3	Alisha	Because when we had put rabbits, invader and grass together the rabbits started to die out quickly	Justifying
4	Alisha	Because there wasn't enough grass since the invader started growing real fast.	Justifying
5	Teacher	Okay. So other evidence or other things you want to say about that?	Questioning
6	Bobbie	The other group had a lot, of the same	Evaluating
7	Student	Yea, yea	Uncodeable
8	Teacher	Well go ahead and say what you thought. Go ahead Bobbie.	Non-argumentative
9	Bobbie	Even when the foxes and rabbits are gone they still had something to eat. Like when we put them in with the rabbits it feels like the grass just went down, automatically.	Justifying
10	Krissy	When we did it, we had rabbits and grass they started eating the grass.	Justifying
11	Krissy	But then some people said that 'well if that is the only thing they had to eat then of course they gonna eat it'	Justifying
12	Students	Laugh	Uncodeable
13	Krissy	So then we put in rabbits and grass and invader and when we did it the first time, rabbits went up and invader and grass went down.	Justifying
14	Student	Damn	Evaluating
15	Student	I see	Evaluating
16	Teacher	Okay, so rabbits went up and invader and grass went down, so that supports your claim. Okay.	Criteria
17	Teacher	Lakisha?	Non-argumentative
18	Lakisha	So we had put on a little bit of rabbits and a lot of invader. So we left them alone and then the rabbits died off still the invader was still doing good without any rabbits,	Justifying
19	Lakisha	They were just eating the grass.	Justifying
20	Teacher	Okay, discussion? Any more discussion about that?	Non-argumentative
21	Students	[silence]	Non-argumentative
22	Teacher	No?	Non-argumentative

Transcript 4.3: Illustrates student presentations during the Invasive Species Whole Class Debate in Ms. B's 2006 class

This transcript exemplifies the type of discussion that occurred during the Invasive Species Whole Class Debate in Ms. B's 2006 class: typically one student in the group would present their claim (i.e., Line 1) and justify it (in Lines 3 and 4). The teacher would then prompt other students in the group to offer additional justifications (Line 5). After each student in the group justified the claim, the Ms. B would offer other students in the class an opportunity to respond (Line 20). The observing students questioned one another only minimally.

When students did question one another during the presentations, the student-to-student interactions were short and taken up by neither the presenting group nor the teacher. In fact, when the teacher directly asked for student discussion in transcript 4.3 (Line 20), the students were silent. In this case, Ms. B accepted the students' silence and quickly moved into a teacher-led wrap-up discussion. While this transcript reveals students presenting arguments, it also reveals challenges: the lack of student-to-student interactions suggest that these students did not substantively attend to one another's ideas.

In the following sections I use analyze the classroom discourse in more detail in order to characterize how this class took up the practice of scientific argumentation. I frame this analysis around the three goals of articulation, persuasion and sensemaking.

4.2.1 Articulation

As described in Section 4.1.1, I examine student engagement in articulation by analyzing the relative frequency with which students contributed utterances that fulfilled various discourse functions necessary for argumentation (i.e., making a claim, justifying an idea etc.). Ms. B's

2006 class made about 9 argumentative utterances per three-minute interval. As discussed earlier, there are no theoretical or empirical measures of how many argumentative utterances one should expect in a middle school science class' argument. Moreover, the variation in how students could engage in articulation of arguments is captured in the analyses of their engagement in sensemaking and persuasion. Consequently, there are no other aspects of the students' argumentative discourse that inform my analyses of their articulation; I cannot analyze their articulation in terms of the aspects that they do and do not emphasize (as I will for persuasion and sensemaking).

Given that the measure of student articulation is one-dimensional, I use cross class comparisons in order to interpret the rate with which students contributed argumentative utterances in a three-minute interval. Given the small N, it is impossible to do statistical comparisons; instead, I use the raw data to indicate trends that are examined more closely in the following sections that explore the students' engagement in persuasion and sensemaking. As shown in Table 4.2, Ms. B's 2006 students made argumentative contributions at lower rates than did students in either of the other two classes that enacted the Invasive Species Whole Class Debate. Moreover, their contribution rate is similar to that of Ms. W's students who were engaged in a teacher-led discussion. Thus, I conclude that students in this class were only minimally articulating arguments.

In the earlier description of my analytical approach, I stated that engagement in sensemaking and persuasion required, first and foremost, that students engage in the articulation of arguments: students can neither build on one another's ideas in order to make sense of a phenomenon, nor persuade others of an idea, without first articulating their ideas. Thus the relatively low levels of articulation in this class indicate that these students neither made sense of the phenomenon under study by reconciling different understandings nor attempted to persuade one another of their ideas. In the following two sections, I examine this conclusion.

4.2.2 Persuasion

I explore student engagement in persuasion by focusing on the two aspects of: 1) defending their ideas and 2) attending to the ideas of their classmates. As I did with the discussion of articulation in this class, I do these analyses by comparing the frequency with which student discourse showed evidence of each of these aspects of argumentation to the frequency with which it explicitly did not. In addition, I provide basic cross class comparisons to help interpret these relative frequencies.

Students in Ms. B’s 2006 class justified about 63% of the ideas that were stated as unique positions for which one could stand (5 justified ideas out of 8 total ideas). For example, Lines 1, 3 and 4 in Transcript 4.3, combine to show a justified idea: in these lines, Alisha justified her claim that the invasive species ate grass. As seen in Table 4.3, this is similar to the relative frequency with which students justified their ideas during the argumentative discussions in all four classes which implies that Ms. B’s 2006 students were as likely to justify their ideas as were the students other classes. The low rate of participation (discussed in Section 4.2.1) in this class shows that, while they were as likely to justify their ideas, as were the students in the other classes, these students weren’t stating as many ideas. Thus, I conclude that when Ms. B’s 2006 students were discussing their ideas they were as likely as students in the other classes to do so in a persuasive way, however this occurred less frequently than it did in the other classes.

The corollary to the 63% justification rate is that 37% of the ideas students discussed in this class were not justified. There are no examples of unjustified claims in Transcript 4.3 because it depicts students formally presenting their final argument and 100% of the ideas discussed during formal presentations in this class were justified. In contrast, students in this class did not justify any of the ideas they discussed during their few 3) Challenging Episodes. Transcript 4.4 provides an example of an unjustified idea that was discussed during a Challenging Episode.

1	Rose	Yea, how do you know that it wasn't eating like, maybe it was eating [rabbits]	Question
2	Krissy	Lakisha said they [rabbits] went up, I said, I mean she said they might have been [eating rabbits]	Crediting author
3	Krissy	but when we did it they [the rabbits] went up.	Justifying
4		[silence]	
5	Teacher	Okay, good question.	Evaluating

Transcript 4.4: Example Challenging Episode in which ideas were not justified

In Transcript 4.4, Rose questions the claim that the invader ate the rabbits put forth by Krissy's group by offering a counter-claim: maybe the invader ate the rabbits. Krissy responds to this question in Line 3 by adding additional evidence to the discussion: the rabbits went up (so the invader must not be eating them). Rose does not respond to Krissy's explanation and she never justifies why her claim—that the invader ate rabbits—might be possible. Thus, this is an example of an unjustified idea.

This analysis indicates that, to the extent that students in Ms. B's 2006 class were articulating arguments, they were presenting them in a way that suggested attention to the goal of persuasion—they defended 63% of the ideas they discussed. However, that they justified their ideas when presenting arguments and not during Challenging Episodes indicates that they were not substantively engaging with one another's ideas (as seen in Transcript 4.4 in which Rose drops her counter-claim instead of pursuing the disagreement).

In fact, as seen in Table 4.4, students in Ms. B's 2006 class responded to one another's ideas no more frequently than they responded to a teacher question during the Invasive Species Whole Class Debate (38%, or 13 out of 34, of the interactions were teacher prompted and 38% were instances of student-to-student interactions). In order to interpret this result, I compare it to the other classes. Students that engaged in the other two Whole Class Debates (Ms. B's 2005 class and Mr. S' class) responded to one another's ideas in more than 70% of their interactions. Using a chi-square test indicates that this is significantly different than the students in Ms. B's 2006 class ($\chi^2(2, n = 208) = 24.7$, and $p < 0.01$).

Thus, I conclude that while Ms. B's 2006 students presented final arguments in a persuasive manner—they defended their claims—they did not attend to one another's arguments. I explore the implications of the students' limited interactions with one another, with respect to their engagement in sensemaking, in the following section.

4.2.3 Sensemaking

As presented in Figure 4.1, sensemaking through argumentative discourse entails three aspects: aspect 2 in Figure 4.1, constructing a claim; aspect 4, attending to one another's ideas; and, aspect 5, revising an argument in light of the other arguments presented.

While one can assume the students in Ms. B's 2006 class success with the initial sensemaking—they presented claims that they had constructed—their classroom interactions reveal little evidence of these more discursive forms of sensemaking. That is, as discussed in Section 4.2.1, students in Ms. B's 2006 class only explicitly engaged with one another's ideas directly in one-third of their interactions (as discussed in the previous section, this is significantly less either of the other Whole Class Debates analyzed in which at least 70% of the student contributions were made in the context of a student-to-student interaction). The lack of student-to-student interactions seen in Ms. B's 2006 class indicates that they were neither making explicit attempts to understand one another's arguments nor in positions to learn from one another.

That students did not respond to one another's ideas, and the brevity of the student-to-student interactions that did occur, indicates that these students were generally not attending to one another's ideas. Consequently, the classroom discourse in Ms. B's 2006 class provides evidence of neither of the final two indicators of sensemaking: they were neither attending and responding to one another's ideas nor revising their claims in light of contradictory arguments.

Figure 4.2 shows the definition of an argument presented in Chapter 1 next to a schematic of how Ms. B's 2006 class adapted this practice.

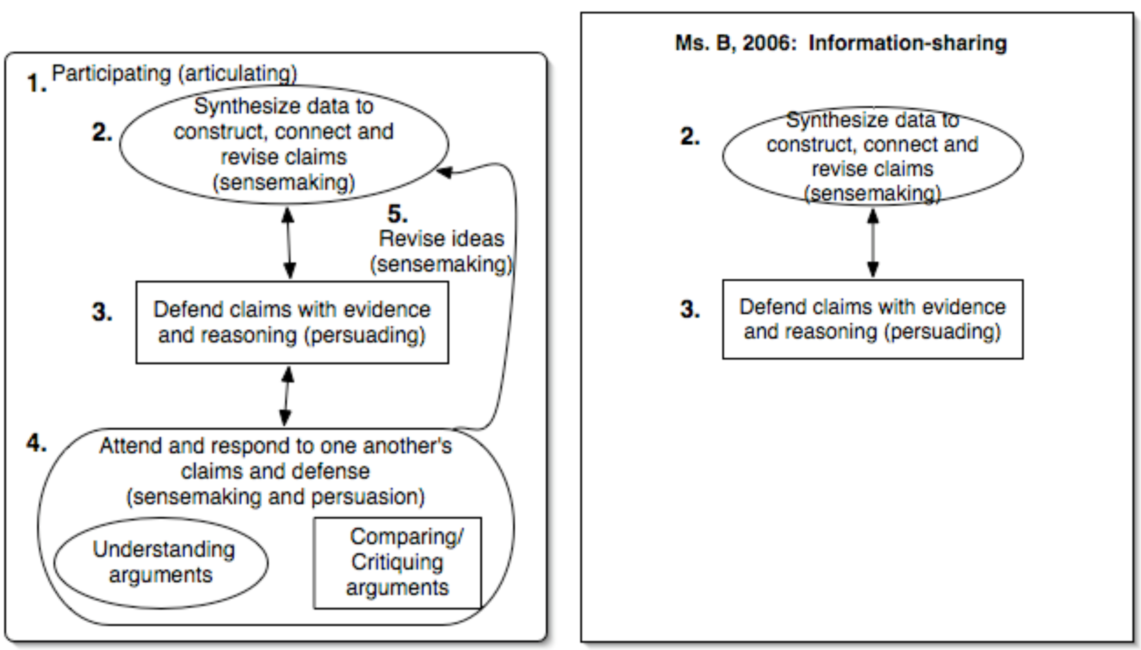

Figure 4.2: Reviewing the definition of argumentative discourse in science classrooms and summarizing the argumentative discourse in Ms. B's 2006 Invasive Species Whole Class Debate

As seen when comparing the two diagrams in Figure 4.2, the discourse in Ms. B's 2006 class reflected two of the three goals of argumentation by exhibiting two aspects of argumentation: they engaged in sensemaking by constructing their initial understandings and in persuasion by defending their claims. However, they neither attended to one another's ideas nor revised their own ideas in light of the discussion. In addition, students in this class participated at relatively low rates and therefore do not show evidence of attention to the goal of articulation. Thus, the argumentative discourse that emerged in this class reveals limited attention persuasion and sensemaking and limited engagement with the goal of articulation. This analysis provides an example of a class that argued by taking up the structure of argumentative discourse without exhibited the aspects of the practice that require more social interactions (they did not substantively attend to one another's ideas).

I refer to their adaptation of the practice as "information-sharing" because the lack of engagement with one another's ideas indicates that the students were reporting—or sharing—their ideas without attending to whether they agreed with one another's ideas. The lack of engagement with one another's ideas and the low levels of participation exhibited by these students are consistent with traditional classroom norms in which the activity goal is to demonstrate expertise, rather than to learn from one another. That the aspects of argumentation that are apparent in the students' discourse—constructing original claims and defending those ideas—enable students to demonstrate their expertise indicates that "information-sharing" largely aligns with traditional school norms and goals rather than those of scientific argumentation. In other words, this class appears to be an example of one in which the classroom community adapted the aspects of scientific argumentation to more closely align with the norms of the classroom, rather than transforming the norms of the classroom to fit with this new practice.

Moreover, this adaptation of argumentation does not align with any of the argumentative forms discussed by Walton (1998), and in that way, this adaptation of the practice may be too far from the accepted forms of argumentation to actually be considered argumentative discourse. That is, it may be that Ms. B's classroom adaptation of scientific argumentation kept too many interaction patterns of traditional classrooms and took up too few aspects of scientific argumentation to be recognizable as such.

I discuss why this class adapted scientific argumentation in this way in Chapter 5. In the following sections, I investigate whether this adaptation was typical of classroom argumentative discourse: do the other classes in this study take up argumentation as an opportunity to "share" without engaging in the other aspects of argumentative discourse? I begin by exploring the Invasive Species Whole Class Debate that occurred in Mr. S' class.

4.3. MR. S

As I did with Ms. B's 2006 class, I characterize the ways in which students in Mr. S' class adopted and adapted the practice of scientific argumentation by first providing an overall description of the Invasive Species Whole Class Debate that occurred in this classroom. I then provide a more detailed analysis of this discussion by characterizing student engagement in each of the three goals of scientific argumentation, individually.

Mr. S began the Whole Class Debate regarding the invasive species by having students move to sit next to students with whom they agreed, but with whom they may not have worked. At the conclusion of this shuffling, there were three large groups of students, divided by their claims regarding the invader's food source. The claims that emerged in this discussion were: the invader eats grass; the invader eats rabbits; and the invader eats foxes, rabbits and grass. After the groups were formed, Mr. S projected a NetLogo graph and told his students that they should use this as data to support their claims. He selected a student to present his group's argument, positioned himself at the back of the room, and gave the presenting student a yardstick with which to point to the projected graph.

During the Whole Class Debate, Mr. S asked the students to rotate presenters such that one student from each group would use evidence from their prior experiences with the NetLogo environment and the projected graph to present an argument, in quick succession. Mr. S expected each round of three presentations to be followed by a question and answer period for all presenters and then to repeat the presentation/questioning pattern until the majority of his students had an opportunity to present their arguments. While the activity was designed such that each group would construct one argument to present, Mr. S' students did not work in their larger groups before the Whole Class Debate. Thus, it was important for Mr. S to allow multiple students from each group to present an argument: no single student could represent the entire group. Due to student eagerness to discuss their differing ideas, the rotation of presenters quickly deviated from the structure provided by Mr. S: students called out during one another's presentations and frequently asked questions between presentations, rather than waiting until the appointed time. This resulted in a heated exchange of ideas in which the students spoke directly to one another identifying evidence and counter evidence for one another's claims while the teacher sat at the back of the room, managing the energy and sound levels in the room. This took approximately 33 minutes.

While the interactions that occurred during these student presentations were lengthy and difficult to represent on paper, Transcript 4.5 presents a taste of these conversations. In this discussion, Isaac asks Tyler, the presenting student, to explain an anomalous data point.

1	Isaac	You said if it eats rabbits, it would die out if it have nothing to eat.	Justifying
2	Teacher	Tyler what he said is that if it eats the rabbits, if the rabbits are at 0 then how is the invader still surviving?	Non-argumentative
3	Student	maybe it ate off grass	Claiming
4	Students	Calling out	Uncodeable
5	Tyler	It don't eat grass	Evaluating
6	Teacher	Shh	Non-argumentative
7	Student	Ahh Tyler, you aint got NUTHIN	Evaluating
8	Tyler	It probably might eat foxes but grass,	Claiming
9	Tyler	see look all the way straight across, you see how it keep going like that, right. See when it [invader] come up, Still the same [the grass].. Still the same… still the same.....	Justifying
10	Students	Calling out	Uncodeable

Transcript 4.5: Illustrates student discourse during Whole Class NetLogo Debate in Mr. S' Class

In this exchange, Isaac questioned Tyler's claim that the invader eats rabbits. As Isaac said earlier in the exchange: "Well, at the end of the graph when the rabbits are dead, how do they [the invasive species] keep going up?" Other students contributed to their exchange with hypotheses such as the invader eating grass (Lines 3 and 4). Tyler disagreed with these alternatives and claimed that the invader ate foxes and rabbits. In Line 9, Tyler supported this with evidence that the invader did not eat grass[14].

Notice that, in this exchange, the teacher only spoke twice, once to restate a student's idea and once to ask the students to be quiet. In addition, we see high student involvement; the teacher asked the students to be quiet because there are many students speaking at once (see lines

[14] He has misinterpreted this data. The correct interpretation is that the steady grass population indicates that something had to eat the grass after the rabbits died out rather than that nothing was eating it.

4 and 10), making it difficult to follow an individual's contribution. Moreover, statements such as the one in Line 7 indicate a student body that is heavily involved in the discussion, evaluating the ideas of the main speakers and determining whether the evidence supports the claims being made. This type of active and frequent participation was common on this day: Mr. S' students made more than four times as many substantive utterances during the Whole Class Debate than Mr. S did himself. Beyond high levels of student participation, this excerpt also demonstrates the types of things students said in this discussion: they frequently justified and evaluated the ideas being discussed.

In the following sections I explore the implications of discourse such as the excerpt exemplified in Transcript 4.5 in order to characterize their adaptation of the practice of scientific argumentation in terms of the three goals: articulation, persuasion and sensemaking.

4.3.1 Articulation

As I did for Ms. B's 2006 class, I use the rate with which students in this class made argumentative utterances as an indicator of whether and to what degree students in Mr. S' class articulated arguments. Through this, I find the frequency with which students contributed utterances that performed functions of argumentative discourse.

In Mr. S' class, students made about 14 substantive argumentative contributions per three-minute interval. As seen in Table 4.2, comparing this to the other classes indicates that Mr. S' students articulated arguments a little more frequently than did Ms. B's 2006 class and a little less frequently than her 2005 class. In addition, this is the second-highest average participation rate of all the argumentative discussions analyzed for this study.

Based on this analysis, it appears that Mr. S' students were engaged with *articulating* arguments; they made contributions that fulfilled the functions of argumentative discourse relatively frequently. In the following sections, I expand this analysis of Mr. S' classroom discourse in order to examine the ways in which the argumentative functions that students contributed indicate attention to these other goals.

4.3.2 Persuasion

As I did with Ms. B's 2006 class, I explore the ways in which Mr. S' students attended to the goal of persuasion by analyzing the two aspects of discourse relate to this goal: 1) presenting ideas in a way that suggests attention to persuasion by justifying them and 2) attending to one another's ideas.

4.3.2.1 WHEN AND HOW DO THESE STUDENTS DEFEND THEIR IDEAS

In this section, I focus on the frequency with which, and the context in which, students justified their ideas. This analysis is consistent with philosophical analyses of argumentation that emphasize the importance of the relationship between claims and justifications (e.g. Toulmin, 1958) as well as relevant science education literature that examines student facility at justifying their claims (e.g. Kuhn, Shaw, & Felton, 1997; Sampson & Clark, in press; Suthers et al., 1997): defending one's ideas is a key aspect of argumentative discourse.

As discussed in Section 4.1, Mr. S' students justified about 65% of the ideas they discussed (24 justified ideas out of 37 total ideas). This is similar to justification rate seen in the other classes: Mr. S' students were as likely to justify their ideas as were the students in other participating classes (see Table 4.3). Moreover, examining when students justified their ideas reveals that they justified about 57% of their ideas when engaged in Challenging Episodes (16 out of 28 ideas in these episodes were justified) and 100% of their ideas when formally presenting their arguments. Thus, even when engaged in these more spontaneous interactions with their classmates (such as the Challenging Episode presented in Transcript 4.5), students were more likely to justify their ideas than not. In other words, students in this class consistently discussed their ideas in a way that suggested attention to the goal of persuasion. That is, the majority of students' discourse in this class enables their audience (other classmates) to determine whether the claims align with the evidence and therefore to determine whether they are persuaded. In this sense, these students are engaging with persuasion.

4.3.2.2 How does the audience attend to one another's ideas?

The previous analysis reveals that students in Mr. S' class can and do defend their claims, both when formally presenting these arguments and when engaging in discussions around them (i.e., Challenging Episodes). These defended claims indicate that students are engaging in persuasion because their contributions are structured in a way that could be persuasive. In this section, I move beyond the analysis of the structure of students' arguments in order to examine the ways in which the audience responded to the arguments. Did students attend to one another's ideas as an audience of them? Did the students engage in the goal of persuasion when being the audience for their classmates' arguments?

I investigate this aspect of the students' argumentative discourse first by exploring the degree to which students responded directly with one another's ideas and then by examining the ways that they do so. Figure 4.3 presents the results of my analysis of the interactions in this classroom and is used to explore the degree to which students explicitly engaged with one another's ideas.

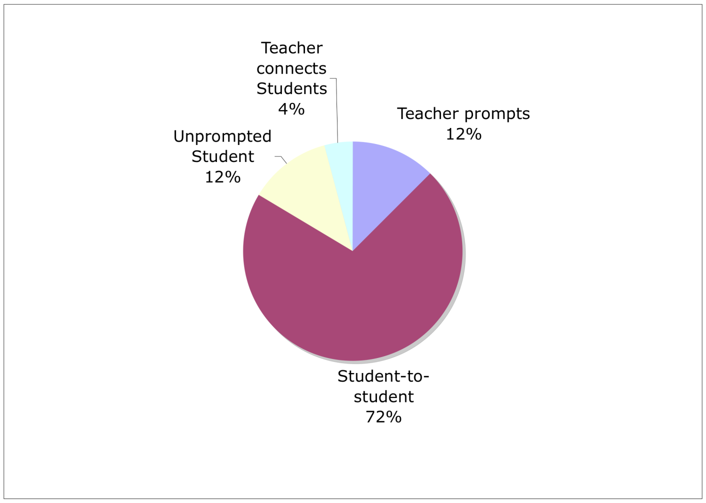

Figure 4.3: Student Interactions in Mr. S' Whole Class Debate

(N = 97 interactions in which students made substantive contributions in 36 minutes of discussion)

The interaction analysis summarized by Figure 4.3 combines the participants' (both students' and teacher's) argumentative contributions in order to elucidate how the contributions were elicited. The student-to-student code identifies those interactions in which a student's argumentative contribution is made in response to a classmate's idea and is unprompted by the teacher. Transcript 4.5 provides an example of the prevalence of student-to-student interactions in Mr. S' class. Figure 4.3 shows that the frequency with which the student-to-student interactions occur in the sample transcript is representative of the rest of the Whole Class Debate: approximately three-quarters (69 out of 97) of the student contributions in Mr. S' class were made in the context of a student-to-student interactions. In order to interpret this result, I compare it to the other classes that participated in a Whole Class Debate (Ms. B's 2005 and 2006 classed). This comparison is shown in Table 4.4 and reveals that students in Ms. B's 2005 class were attending and responding to one another's ideas at relatively high rates.

Moreover, these student-to-student interactions break from the traditional interactions in which students respond primarily to teacher questions (Cazden, 1988; Lemke, 1990; Mehan, 1979). Consequently, this relatively high percentage of student-to-student interactions indicates that students in Mr. S' class were taking up aspects of scientific argumentation—they were attending to one another's ideas.

In order to understand how students were responding to one another's ideas, I turn to the functional analysis of student utterances. Figure 4.4 reveals the relative frequency with which students' utterances served each of the functions of argumentation (defined in Chapter 2). In this discussion, I am particularly interested in the relative frequency with which students made evaluative and questioning comments. I am interested in these functions because they are the most direct way that an individual can respond to another's ideas.

Moreover, from an analytical perspective, the majority of the students' justifications and claims that were in direct response to an idea made that connection explicit by also evaluating or questioning it. For example, if a student said: "I (dis)agree with you because [of this information]" the student would be both evaluating the original assertion (by agreeing or disagreeing) and justifying that evaluation. Similarly, a student might question a classmate by saying: "Why do you think that, because I think this [alternative claim]." In this case, the student would be questioning their classmate's ideas and offering a counter-claim. Thus, in looking at questions and evaluations I am looking at how the students explicitly framed their responses to one another. Did they acknowledge a disagreement by negatively evaluating a classmate or did they question one another in order to determine why they disagreed?

I use Transcript 4.6 to demonstrate the difference between evaluating and questioning an idea. Before this excerpt, the students had been discussing the possibility that the invader ate rabbits. One student pointed out that the invader had to eat more than rabbits because the invader survived after the rabbit population died-out. Another student posited that the invader ate foxes and rabbits. Kevin disagreed with that claim—he believed the invader ate grass.

1	Kevin	I don't think it was eating foxes,	Evaluating
2	Kevin	but it was probably eating some of the grass.	Claiming
3	Kevin	Because even when the rabbits died out the grass, it kind of stayed the same.	Justifying

Transcript 4.6: Showing a student's evaluative contribution

In Line 1, Kevin evaluated his classmate's claim by stating that he disagreed with the idea that that the invader eats foxes. He then offered an alternative claim—that the invader ate grass (Line 2) and justified that possibility (Line 3). Of course, Kevin's objection could have been stated as a question, rather than a justified evaluation. Kevin could have asked: "if the invader eats foxes why didn't the grass population increase when the rabbits died?" This is the difference that I am examining by comparing the relative frequency with which students made questioning and evaluative utterances.

As seen in Figure 4.4, 22% of the students' utterances were an evaluation (37 out of 172) of another idea while 9% were questions (15 out of 172).

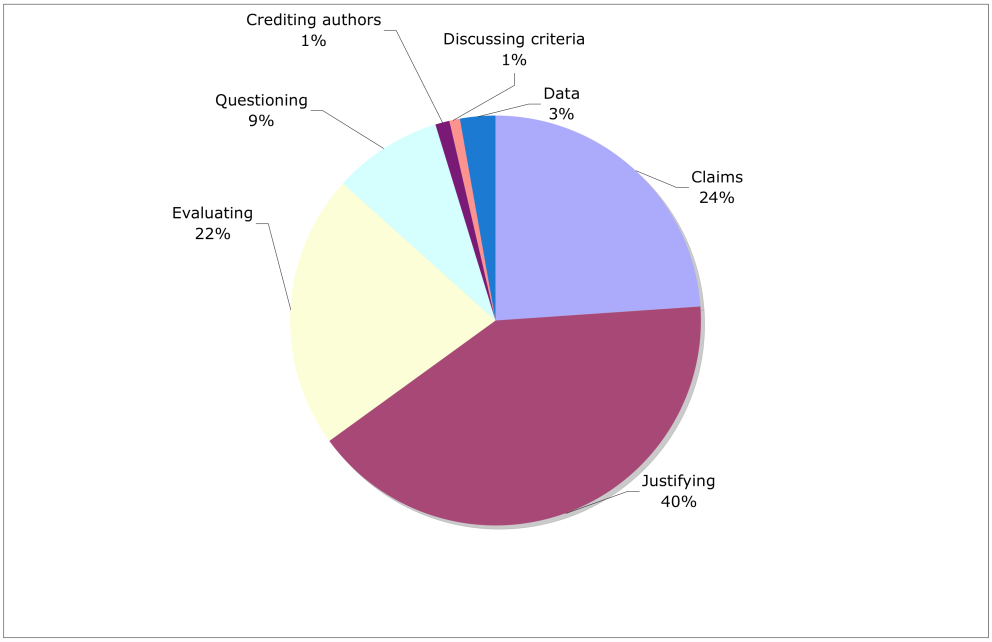

Figure 4.4: Function of student utterances in Mr. S' Whole Class Debate.

(N = 172 substantive student utterances in 36 minutes of discussion)

This means that these students were twice as likely to agree or disagree with one another, as they were to question one another's ideas. Moreover, examining the functions of Mr. S' utterances, provides additional evidence that the emphasis on evaluation over questioning may be more than a side effect of the students' phrasing: Mr. S is the only teacher to contribute more explicitly evaluative statements than he does questions. Therefore, in this class, both the teacher and the students evaluate more than they question. That the pattern of emphasizing evaluations over questions is consistent across teacher and student contributions suggests that the evaluations seen in exchanges such as Transcript 4.6 are indicators of classroom norms.

This emphasis on evaluative contributions indicates that this class was actively determining whether they were convinced of one another's ideas. In this way, they were engaging in persuasive discourse. That is, as a statement of agreement, evaluations are a way for participants to state whether they are persuaded of an idea. Thus, these evaluations indicate engagement in the role of audience member in persuasive interactions.

This analysis reveals evidence of both aspects of the goal of persuasion. First, the students consistently presented their arguments in a persuasive manner by defending them. Second, Mr. S' students actively attended to one another's ideas. Moreover, when attending to their classmates' arguments, students did so by determining whether they were persuasive. This engagement offers a distinct transformation of typical classroom interactions in which students interact with their teacher and do not engage with one another's ideas. I turn now to examine the ways in which students in Mr. S' class adopted the practice of scientific argumentation by focusing on their sensemaking through argumentative discourse.

4.3.3 Sensemaking

I explore the ways in which students in Mr. S' class engaged in sensemaking by looking at the three aspects of this goal discussed earlier: 1) constructing a claim, 2) attending to one another's ideas and 3) revising an argument in light of the other arguments presented.

As seen in Figure 4.3, Student Participation Patterns in Mr. S' Whole Class Debate, the students in this class were clearly active audience members of one another's arguments: almost three-quarters of the interactions that involved student contributions were a direct response to a classmate's idea. In other words, these students were frequently engaging with one another's ideas. Moreover, 22% of their utterances were an evaluation of the ideas being discussed (37 evaluations out of 172 utterances) and the students demonstrated facility with identifying evidence that contradicted one another's claims (as seen in Transcripts 4.5 and 4.6). Both of these acts are indicative of the students' sensemaking in the broad sense: students needed to make sense of one another's arguments and the available evidence in order to evaluate and contradict one another. Thus, the previous analyses provide evidence that students in this class engaged in the first two aspects sensemaking: they constructed their initial claims and attended to the ideas of their classmates.

In this section, I use the analysis of the Challenging Episodes, presented in Figure 4.5, to extend this analysis in order to examine whether and how students engaged in the third aspect of sensemaking: do students construct more robust explanations of the phenomenon under study as a result of this discourse? In particular, in this section, I examine the ways in which students resolved the Challenging Episodes in this class—resolved their disagreements—in order to gain insight into whether they revised their understandings in response to the argument in which they participated. Figure 4.5 reveals that, in Mr. S' class, few of the challenges were resolved. That is, the majority (13 out of 20) of the Challenging Episodes were concluded with no reconciliation of the differing ideas.

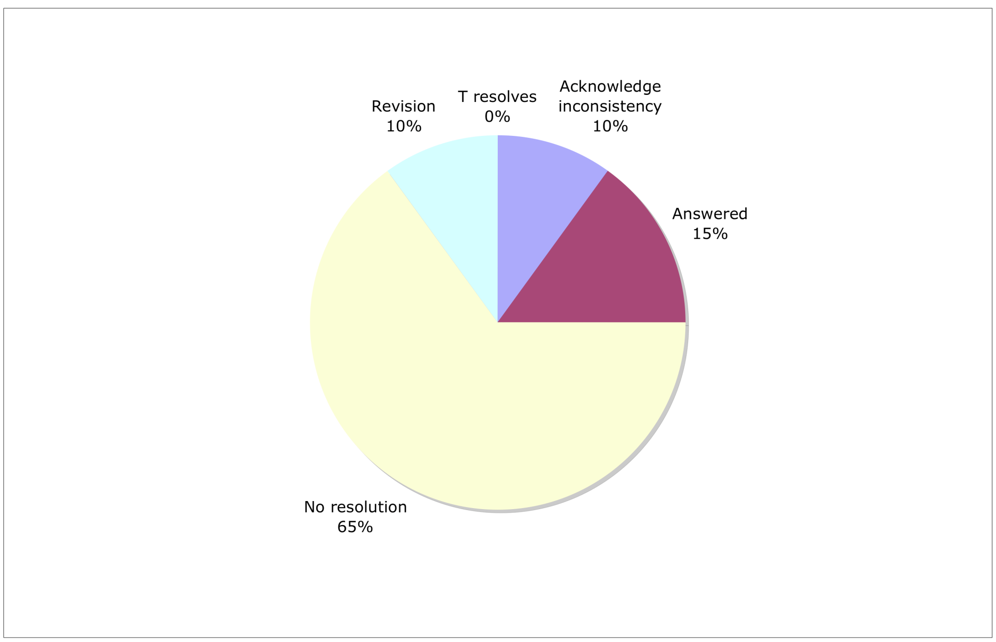

Figure 4.5: Conclusion of the Challenging Episodes in Mr. S' Whole Class Debate

(N = 20 Challenging Episodes, taken from 36 minutes of discussion)

An example of an unresolved Challenging Episode is presented in Transcript 4.7. Throughout this exchange both Tyler and Larry stood at the projected graph, pointing to specific areas on the graph and debating their interpretations of this evidence. This exchange began with Larry stating that the invasive species eats all the organisms that are native to the environment (foxes, rabbits and grass) and Tyler (apparently forgetting the concession he made about 15 minutes earlier in the discussion that the invader might eat grass—shown in Transcript 4.5) arguing that it does not eat foxes.

1	Larry	Look, look Tyler, look, when the foxes went down right, the foxes went down right here,	Justifying
2	Larry	and then the invader went up, they ate the [inaudible] the rabbits was already dead	Justifying
3	Larry	so they fed on the foxes	Claiming
4	Tyler	No	Evaluating
5	Larry	Yes	Evaluating
6	Tyler	No	Evaluating
7	Larry	Yes	Evaluating
8	Tyler	Because look, look right here, it [the foxes] went right up, foxes went up.	Justifying
9	Tyler	You can see that, right?	Justifying
10	Larry	The foxes ate the rabbits too…	Uncodeable
11	Student	So that is why the rabbits	Uncodeable
12	Larry	The foxes ate the rabbits too…	Uncodeable
13	Tyler	Right there, right there. But you say they eat all and I'm on the foxes case. Why that went up, then that was right there…	Justifying
14	Larry	The foxes ate the---	Uncodeable
15	Tyler	…then when that went down a few times later	Questioning
16	Larry	the foxes was eating the invader, and then, uh…	Claiming
17	Teacher	Okay, you guys have a seat, now we're gonna do…	Non-argumentative

Transcript 4.7: Example of an unresolved Challenging Episode

Transcript 4.7 reveals students debating their interpretations of the data, with respect to their differing claims. Throughout this exchange each student presents evidence that supports their opposing claims and the teacher ends the exchange by asking them to "have a seat." This transcript provides an example of an unresolved Challenging Episode. That is, in this example, the teacher's move to end the students' discussion means that the episode ended before the students reconciled their different interpretations of the data. Thus, this Challenging Episode concluded without resolving the disagreement. That 65% (13 out of 20) of the Challenging Episodes concluded in this manner and that students explicitly revised their understandings in only 10% (or 2 out of 20) of the Challenging Episodes suggests that this class rarely reconciled their differences.

The lack of reconciliation of the differences implies that the students did not engage in the third aspect of sensemaking: they did not construct the most complete explanation of the phenomenon by learning from one another's arguments. One student appeared to challenge this trend by attempting to reconcile the cross-group differences at the end of the debate: as a result of the class' argument, Joshua was convinced that each of the possible claims could be disproved, including his own. In other words, Joshua appeared to believe that all claims were equally faulty. In Transcript 4.8, Joshua discusses his difficulty with choosing the best claim, in light of all of all of the presented arguments.

1	Joshua	If, for the rabbit group, uhmm, I think, ‘cuz I’m kinda getting confused now that everyone made their point,	Non-argumentative
2	Teacher	Are you?	Non-argumentative
3	Joshua	Yea, because everyone got a good point in some way. They got a good point.	Evaluating
4	Teacher	But only one of them can be right though, you know that, right?	Criteria
5	Joshua	Yeah I know only one of them is right,	Non-argumentative
6	Joshua	because when the invader went up, the rabbits went down,	Justifying
7	Joshua	and then every time, like right here [points at graph], when the invader went up, the foxes went down.	Justifying
8	Joshua	So everything going down for some reason, and um..	Claiming
9	Teacher	That is true, everything is going down and up for a reason.	Evaluating
10	Joshua	And I think, this my final answer. And I think, I don't know what it eats. This is my final answer: I dunno.	Non-argumentative
11	Teacher	Now, you had the same question yesterday. You started out saying it was what, rabbits? [the invader ate rabbits]	Non-argumentative
12	Joshua	Foxes [the invader ate foxes]	Non-argumentative
13	Teacher	And then you changed to?	Non-argumentative
14	Joshua	Grass. Now I'm about to change to [the invader eats] all	Non-argumentative
15	Teacher	Now you about to change	Non-argumentative
16	Joshua	Because, Mr. S it is confusing	Non-argumentative
17	Teacher	That is okay, Joshua. It’s not an easy thing to do, okay? And this is what I'm trying to get across to you guys: it’s not an easy thing to do. And even though you have evidence, it’s how you interpret the evidence.	Criteria
19	Teacher	So lets go on, who was next?	Non-argumentative

Transcript 4.8: Joshua's struggles with reconciling the arguments

This exchange demonstrates that Joshua determined that each of his classmates' arguments could be disputed. This apparently led him to attempt to reconcile the differences across the student groups—he attempted to synthesize of all of the available data. However, this was challenging and he was unable to do it. Mr. S acknowledged this challenge and then moved on, thereby failing to support Joshua's reconciliation of the apparently contradictory evidence. This exchange reveals an individual student attempting to build on his classmates' ideas; Joshua was apparently attempting to revise his understandings in light of the argumentative discussion. Unfortunately, neither the teacher nor his classmates took-up his attempt. That is, while this exchange provides evidence of a single student attempting to reconcile differences, it was not taken-up in the classroom discourse and it therefore appears that this class, as a whole, did not engage in this aspect of sensemaking.

Figure 4.6 uses the elements of argumentative discourse to depict this characterization of the argumentation that occurred in Mr. S' class.

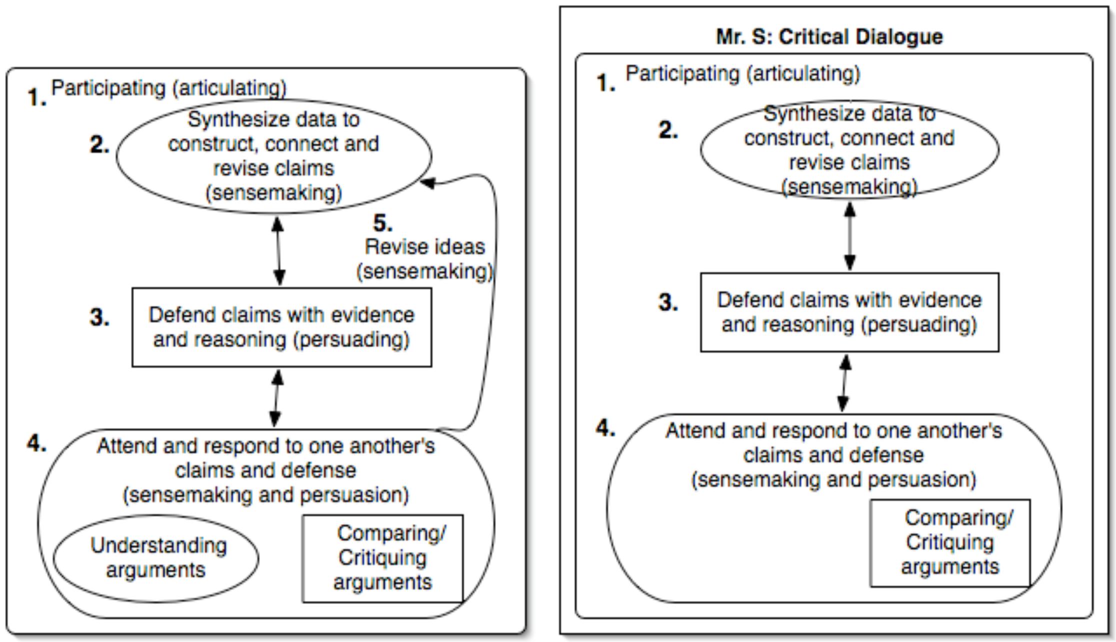

Figure 4.6: Reviewing the definition of argumentative discourse in science classrooms and summarizing the argumentative discourse in Mr. S' Invasive Species Whole Class Debate

Figure 4.6 compares the analytical framework with the characterization of argumentation in Mr. S' class thereby revealing how this analysis has unpacked the element of "attending to one another": analyses of Mr. S' students' discourse reveal that one way students can show attention to the goal of persuasion through this discourse is to compare across arguments in order to determine whether they are persuaded by them. Recall that the oval in this diagram indicates that the an aspect is an indicator of student attention to the sensemaking goal, the square is used to show that the aspect pertains most directly to persuasion and the rounded square shows that the aspect is an indicator of attention to both goals. I have placed "comparing arguments" in a rectangle because it is one clear way to demonstrate attention to persuasion: it is how individuals communicate whether they were persuaded. In addition, I have placed this new discourse characteristic within Aspect 4, attend and respond to one another's claims and defense, because it clarifies the form that response could take: in Mr. S' class students responded to one another's ideas by comparing and critiquing them.

Beyond highlighting the nuanced understanding of "attend and respond to one another's claims and defense" comparing these two figures reveals that students in Mr. S' class engaged in many of the aspects of argumentative discourse. They: participated; constructed claims; defended their claims; and attended to one another's ideas. However, they did not engage in all aspects of sensemaking: they rarely took information gleaned from their classmates' arguments to revise their own. Thus, these students engaged in all of the aspects of articulation and persuasion and some of the aspects of sensemaking.

Following Walton's scheme, I call this form of argumentative discourse critical or persuasion dialogue. As defined by Walton,

> Persuasion dialogue is the type of conversational exchange where one party—the proponent—is trying to persuade the other party—the respondent –that some particular proposition—the thesis—is true, using arguments that show or prove to the respondent that the thesis is true. The respondent is doubtful that this proposition can be proved or shown to be true, and this doubt stems from the respondents' conviction that an opposed proposition – the negation or opposite of the thesis of the first party – is true (Walton, 1998, p. 37).

A critical dialogue is a special form of persuasion dialogue that Walton adopted from van Eemeren and Grootendorst's (1984) work. In critical dialogue the work of proving one's own thesis to be true is fulfilled by identifying problems –criticizing—the opposing arguments. The discourse in Mr. S' class aligns with these characteristics of a critical dialogue: students were debating their opposing thesis by demonstrating why their classmate's theses were false.

The analyses of Ms. B's 2006 and Mr. S' respective class' argumentative discourse have provided examples of two different adaptations of the practice of scientific argumentation: Ms.

B’s 2006 students engaged in information-sharing while Mr. S’ students engaged in a critical dialogue about one another’s arguments. In the following two sections I extend this analysis by examining the argumentation that occurred in two additional classes: Ms. B’s 2005 class and Ms. W’s class.

4.4 Ms. B, 2005

In 2005, Ms. B’s class also engaged in the Whole Class Debate regarding the invader’s food. In many ways, Ms. B’s students took up this activity in a manner that was quite similar to the discourse observed in Mr. S’ room, however these enactments also exhibit striking differences. Similar to Mr. S’ students, Ms. B’s students were actively engaged with one another’s ideas. However, the discourse in Ms. B’s 2005 class does not exhibit the critical dialogue seen in Mr. S’ class. In this section, I depict the argumentative discourse that emerged in this class and then provide more careful analyses of the classroom discourse, in order to unpack this class’ adoption and adaptation of scientific argumentation.

In 2005, Ms. B worked with another researcher and myself to create activities that fostered argumentative discourse. The work we did in 2005 influenced the curriculum used in the 2006 enactments. Two components of the argumentative activity seen in this class but not apparent in the other enactments examined for this study were adapted from Herrenkohl and Guerra’s design work, and are discussed below: the class created a “Question Board” to guide their interactions during the Whole Class Debate and students were provided with explicit roles to foster student-to-student discourse.[15]

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[15] These two supports were included in the 2006 curriculum as suggestions to the teacher. But they were not emphasized and neither Mr. S nor Ms. B used them that year.

Before the Invasive Species Whole Class Debate, Ms. B led her students in a discussion in which they identified general questions they could use to question one another's arguments. For example, she asked her students:

> So, what kinds of questions would you want to ask the group that is up there presenting say the [invasive species is a] coyote. What kinds of questions would you want to ask them, if you weren't in their team and you wanted to know like why they thought that was a good idea (Classroom Observation, April 25, 2005).

These questions were posted on a whiteboard, the Question Board, so that the students could refer to them throughout the debate. Throughout this discussion, Ms. B supported her students in identifying questions that emphasized appropriate epistemic criteria, such as validity of evidence and aligning with the scientific community's (in this case, the class') agreed upon scientific principles. Ms. B did this by asking leading questions, providing examples of appropriate questions, and revising their suggestions to more closely meet her goals. At the conclusion of the discussion, the final Question Board included questions such as: "what evidence do you have that shows that" "how do you know that" and "how does that prove your hypothesis."

The Whole Class Debate regarding the invasive species food source occurred the day after the students created the Question Board. This debate was much more structured than the debate in Mr. S' room. For example, unlike Mr. S' class in which groups were created moments before the debate began, groups in Ms. B's class were established before the debate and students entered the activity with a prepared argument. In addition, Ms. B gave students roles to guide their participation during the debate: during each presentation the groups were told that they were *presenting* their argument, *questioning* the presenters or silently *observing*. The groups rotated through each role so that all students performed all roles. Thus, the Whole Class Debate was a series of four students presenting, four students questioning and eight students quietly observing. Possibly as a result of this structure, Ms. B's students largely limited their participation to times when it was their responsibility—or role—to present or question.

This aspect of "more structured" can be seen in the length of the student-to-student interactions. Instead of the lengthy back-and-forth interactions exemplified in the transcripts from Mr. S' class, Ms. B's students typically engaged in something that appeared to be more like a student-led triadic dialogue than a spontaneous interaction: student-questioners asked a question (typically this question came from the Question Board), presenters answered it, questioners acknowledged the answer, and then the conversation moved on to another question or another presentation. These answers were rarely debated or discussed at length. Transcript 4.9 illustrates this type of interaction.

1	Questioner	How do you know they [the invasive species] actually ate the foxes?	Questioning
2	Presenter	Because they [the foxes] died.	Justifying
3	Questioner	Okay, another question…	Non-argumentative

Transcript 4.9: Example student-to-student interaction in Ms. B's 2005 class

The interaction depicted in Transcript 4.9 illustrates a student-to-student interaction in Ms. B's 2005 class in which the students responded to one another without engaging in a lengthy discussion. In the follow sections, I provide a more detailed analysis of the discourse that occurred in Ms. B's classroom in order to explore the implications of these and other discourse patterns with respect to the students' engagement in the three goals of scientific argumentation: articulation, persuasion and sensemaking.

4.4.1 Articulation

As discussed in the earlier analyses, I explore the degree to which students engaged in the articulation of argumentative discourse by focusing on the frequency with which they made contributions that fulfilled argumentative functions. In 2005, Ms. B's students made about 19 argumentative contributions per three-minute interval. As seen in Table 4.2 no other class exhibited a higher rate of participation. This comparison makes clear that the students in Ms. B's 2005 class were making contributions that performed the functions needed for argumentative discourse at relatively high rates. I therefore conclude that these students engaged in the goal of *articulation*.

4.4.2 Persuasion

In the following two sections, I explore how Ms. B's 2005 students engaged in the two aspects of persuasion identified earlier: defending ideas and attending to the ideas of their classmates.

4.4.2.1 WHEN AND HOW DO THESE STUDENTS DEFEND THEIR IDEAS?

Examining the justification-pattern of the students' discourse in Ms. B's 2005 class reveals that they were approximately as likely to defend their ideas, as were students in the other classes (seen in Table 4.3). Comparing student presentation of formal arguments to their Challenging Episodes reveals that, similar to Mr. S' class, students in Ms. B's 2005 class justified about 5 of the 6 ideas (or 80%) discussed during formal presentations and 6 of the 11 (55%) ideas discussed during the Challenging Episodes.

While students in Ms. B's 2005 and Mr. S' classes appear to be justifying their ideas at similar rates in both presentation and challenging contexts, these two classes differed in the ways in which claims were justified. Recall that the majority of the Challenging Episodes in Mr. S' class entailed an exchange of ideas in which the presenters and challengers each contributed claims and/or justifications. In Ms. B's 2005 class, on the other hand, the vast majority of the Challenging Episodes (12 of 19) were instances in which no claim was stated. Instead, these episodes began with the challenger asking a question (which may or may not include an implicit claim) and ended when the presenting students answered that question. Thus, the similar rates of justification belies a complication: Mr. S' students responded to challenges by engaging in a lengthy exchange in which both the original idea and the opposing ideas were justified; in contrast, in Ms. B's 2005 class, original ideas were justified during the Challenging Episodes but opposing ideas were rarely made explicit and were therefore not justified (as seen in Transcript 4.9, in which the Questioner did not offer an opposing claim). I explore this difference at more length in the following section.

4.4.2.2 How does the audience attend to one another's ideas?

The previous analysis indicates that students in Ms. B's 2005 class presented their ideas in a way that suggests attention to the goal of persuasion. In this section I explore how the students engaged in persuasion as audience members of an argument—did they attend to one another's ideas and if so, how?

Figure 4.7 illustrates the results of the interaction analysis for Ms. B's 2005 Whole Class Debate. This analysis combines participant (both student and teacher) utterances in order to examine the social context in which the utterances were contributed. Figure 4.7 highlights the different relative frequencies with which student contributions were prompted by Ms. B, elicited by another students' ideas and made spontaneously. This analysis reveals that the majority of the student contributions in Ms. B's 2005 class occurred in the context of a student-to-student interaction.

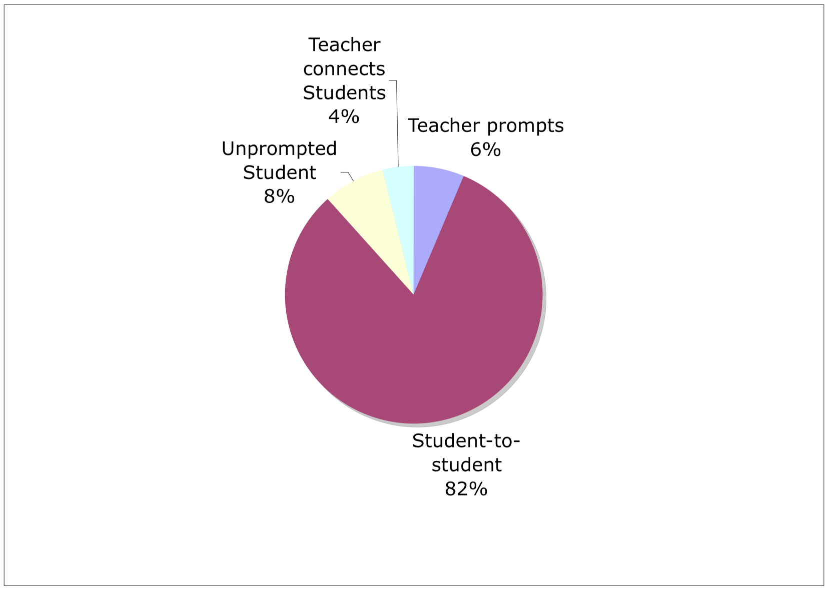

Figure 4.7: Student interactions in Ms. B's 2005 class

(N = 77 taken from the 24 minute discussion)

As seen in Figure 4.7 students in Ms. B's 2005 class participated in student-to-student interactions in 82% of the interactions that involved their substantive contributions (69 out of 77). As I did with the earlier analyses, I compare the discourse in Ms B's 2005 class to the argumentative discourse in the other classes in order to interpret this result. This comparison is presented in Table 4.4 and reveals that this is similar to the rate with which students in Mr. S' class responded to one another's ideas during their Whole Class Debate, and is higher than the other class in which students participated in a Whole Class Debate (Ms. B's 2006 class). I therefore take this as strong evidence that the students in Ms. B's 2005 class were attending and responding to one another's ideas at relatively high rates.

The interaction analysis leaves open questions regarding what students were saying when interacting with one another. Figure 4.8 addresses this question by presenting results of the functional analysis of Ms. B's 2005 students' utterances.

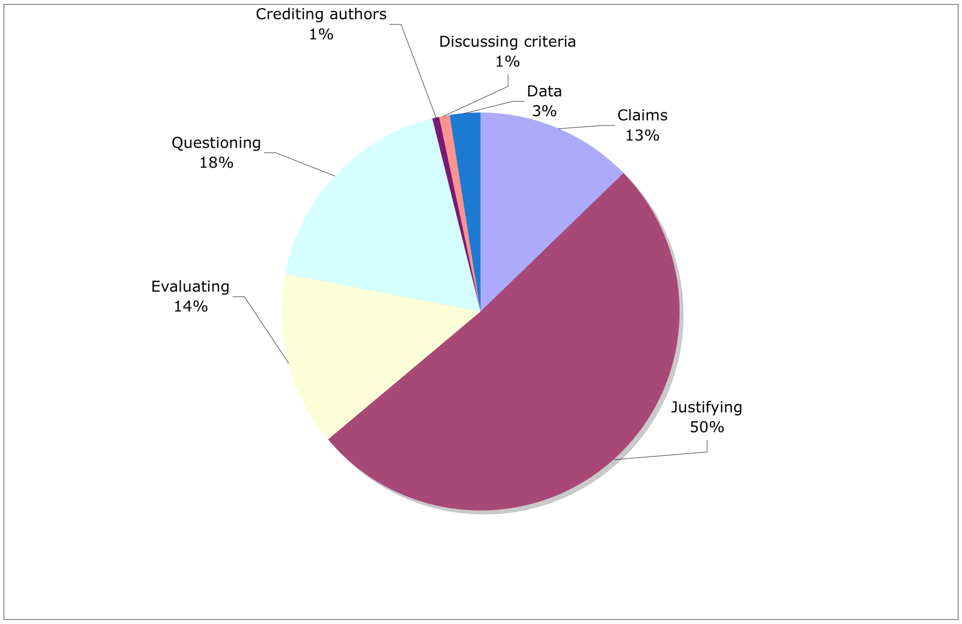

Figure 4.8: Function of students' utterances in Ms. B's 2005 Whole Class Debate

(N = 155 utterances taken from the 24 minute discussion)

As seen in Figure 4.8, Ms. B's 2005 students contributed evaluative (22 out of 155) and questioning (28 out of 155) utterances at equivalent rates. As seen in Table 4.5, this is a different emphasis than the one seen in Mr. S' class in which the students were twice as likely to evaluate one another's ideas as they were to question them.

In addition, examining the rate with which students made claims (shown in Table 4.5) indicates that Ms. B's 2005 students made about half as many claims as did Mr. S' students (13% compared to 24%). This difference is made even more stark when focusing on the Challenging Episodes: about 9% of Ms. B's 2005 students' utterances during Challenging

Episodes were claims while about 22% of Mr. S' students' utterances were claims in the same context. This difference can be seen in the comparison between Transcripts 4.6 and 4.10. In Transcript 4.6, Kevin both evaluates his classmate and offers a contradictory claim to support his negative evaluation. In contrast, in Transcript 4.10, the questioner asks a question without identifying an alternative interpretation of the data.

This focus on questioning over evaluating and contradicting can be seen in Transcript 4.10. This exchange begins after Janelle and Mikaili finished defending their group's claim that the unknown invasive species was a vegetarian (and hence ate grass). Transcript 4.10 picks up when one of the assigned student questioners challenged that claim.

1	Questioner	How do you know that your invader is a vegetarian?	Questioning
2	Mikaili	Because they…	Uncodeable
3	Janelle	Because it only ate grass.	Justifying
4	Janelle	The foxes didn't die at all, only when the invader died.	Justifying
5	Mikaili	And we made sure of that, because we put the invader and the foxes in there alone with no rabbits to make sure that that is what was going on.	Justifying

Transcript 4.10: Example of a typical Challenging Episode in Ms. B's 2005 class

Transcript 4.10 is representative Challenging Episodes that occurred in Ms. B's class and it reveals a striking pattern: Ms. B's students rarely offered contradictory claims and justifications when challenging one another. Instead they asked questions[16]. For example, in Line 1 the questioner asks the presenting students to defend their claim that the invader is a

[16] It is important to note that Ms. B asked for this. On the rare occasion that a student offered a contradictory claim or justification, Ms. B would prompt them to ask questions, saying that the student questioners would have time to share their own thoughts when their group presented. I do not include this explanation in this discussion because, regardless of the reason behind it, the students' discourse indicates how they engaged with the practice. Chapter 5 will explore why students did these things.

vegetarian. Unlike the Challenging Episodes in Mr. S' class, this question offers neither an alternative interpretation of the data—it does not present a contradictory claim—nor contradictory evidence. Instead, this question simply asks for more information. When combined, Transcript 4.10 and the frequency with which students made claims during Challenging Episodes suggest that Ms. B's 2005 students were explicitly contradicting one another relatively rarely (when compared to Mr. S' students).

Through this analysis, we see that—instead of explicitly evaluating or contradicting their classmates—Ms. B's 2005 students asked one another for more information. In the following section in which I analyze the ways in which students in this class engaged in sensemaking, I address the implications of this apparent emphasis on questioning. For the analysis of Ms. B's 2005 class thus far, the important findings are the lack of focus on evaluation and contradiction and its implications with respect to student engagement with the goal of persuasion. That is, the relatively low frequency with which students evaluated and contradicted one another's ideas suggests that, when being an audience member, students in this class did not show attention to all aspects of persuasive discourse: they did not compare and critique one another's arguments.

Combining these analyses of the students' discourse reveals a new form of persuasion: Ms. B's 2006 students attended to persuasion by defending their claims; Mr. S' students both defended their claims and attended to one another's claims by comparing and critiquing them; Ms. B's 2005 students, on the other hand, defended their claims and attended to one another's ides but did not evaluate them. That is, when in the role of audience member, these students appeared less engaged with the persuasive goal; while these students were clearly attending to one another's ideas (as seen in their frequent responses to one another), they rarely indicated whether they were persuaded of one another's ideas. In the following section I explore what the students' attention to one another's ideas indicates about their sensemaking.

4.4.3 Sensemaking

I explored students' sensemaking in the other two classes by looking at their engagement with: 1) constructing a claim, 2) attending to one another's ideas and 3) revising an argument in light of the other arguments presented. The students' ability to engage in the argumentative discourse provides evidence that they constructed claims. Thus, in the following two sections I focus on how students in Ms. B's 2005 class attended to one another's ideas and revised their understandings in light of these differing arguments.

4.4.3.1 HOW DO THESE STUDENTS ENGAGE IN SENSEMAKING BY ATTENDING TO ONE ANOTHER'S IDEAS?

Recall that, in 2005, Ms. B's students were less likely to make claims and evaluative statements than were Mr. S' students. Instead, Ms. B's students asked questions. Transcript 4.11 exemplifies this attention to questioning one another. This transcript shows the first two questions to follow a presentation in which the students argued that the invasive species was a coyote and ate foxes.

1	Questioner 1	How did you find out that the invaders were eating the foxes instead of the other way around?	Questioning
2	Presenter 1	She just said that.	Crediting author
3	Presenter 4	Basically when we, we gathered that when the fox population was high, the invader population was low. And when the invader population was high…	Justifying
4	Questioner 1	Yea, like I know that. But I'm saying that: what did you put [how did you set up the computer model]? Did you put the invader and the foxes on the screen without anything else? In order to get that?	Questioning
5	Presenter 4	No.	Data

6	Presenter 3	That was when all the other animals died out and it was just them 2 left.	Justifying
7	Questioner 1	Okay	Non-argumentative
8	Questioner 2	Wouldn't you think that a coyote or fox would be too small to eat a coyote unless it was dead? And it had already. Yea. So I don't, I don't understand how a a fox and a coyote being alive, how a fox could eat a live coyote.	Questioning

Transcript 4.11: Students questioning one another in Ms. B's 2005 Whole Class Debate

Although these questioners disagreed with the presenters (as indicated in their presentation of their own argument), they responded to their classmates' argument by asking questions (in Lines 1 and 8) that pushed the presenters to clarify both the evidence (in Lines 3 and 6) and the logic of their claims (in response to Line 8). These neutrally framed questions illustrate that rather than using the Challenging Episodes to put forth a contradictory argument, students in Ms. B's 2005 class used the Challenging Episodes to make sense of one another's argument. That is, these students identified potential problems with the argument and asked questions that pushed on those concerns.[17]

Unsurprisingly, the ways in which students framed their challenges to one another—as questions—influenced the ways in which the Challenging Episodes were resolved and, consequently, my analysis of the students' engagement in with the final aspect of sensemaking:

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[17] It is possible that the activity and scaffolds (e.g., the Question Board) elicited the students' questions, rather than their attention to one aspect of argumentation over another. In this case, the students would have been asking questions simply to fulfill the demands of the task, rather than to engage in the practice of scientific argumentation. However, regardless of their motivation, the emphasis on questioning results in a class in which the students' contributions align with the types of contributions necessary for making sense of one another's arguments. As such, I conclude that students in Ms. B's 2005 class were explicitly engaged with making sense of one another's arguments.

revising their understandings in light of one another's arguments. In the following section I explore this aspect of their argumentative discourse.

4.4.3.2 How do these students respond to their differing understandings?

Scientific argumentation is frequently hailed as a tool to foster student engagement in sensemaking through discourse; it is a discourse form that researchers and teachers hope will motivate students to attend to weaknesses in their understandings and revise them accordingly (e.g. Driver et al., 2000; Jimenez-Aleixandre et al., 2000; Lehrer & Schauble, 2006; Scardamalia & Bereiter, 1994; Warren & Rosebery, 1996). In this section, I explore the degree to which students in this class achieved this ideal by analyzing the ways in which they responded to Challenging Episodes—those episodes in which one participant questioned or challenged the ideas of another. This analysis examines the Challenging Episodes to find explicit instances in which students revised their understandings as a result of the classroom discourse.

As seen in Figure 4.9, more than two-thirds (13 out of the 19) of the Challenging Episodes in this class were resolved by students "answering" the question. Transcript 4.11 demonstrates this resolution by answering. In this excerpt, the presenters answered the questions without reconsidering their claims. In addition, the questioners accepted the answers without acknowledging that they disagreed with the presenters' claim. In fact, neither the questioners nor the presenters appeared to decide that their classmates' ideas were compelling enough to revisit their own. Instead, the questions were answered, (Lines 3 and 6) and accepted (in Line 7) such that the discussion could move on to the next question or presentation.

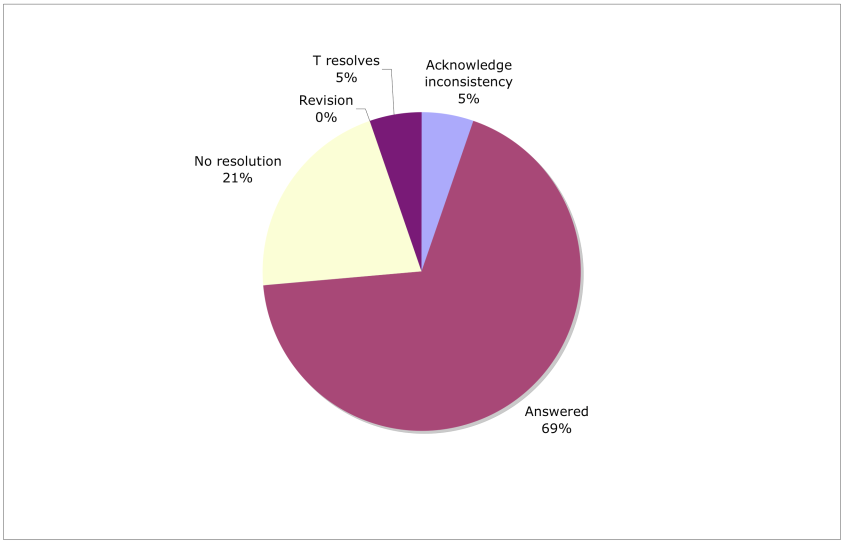

Figure 4.9: Conclusion of the Challenging Episodes in Ms. B's 2005 class

(N = 19 taken from the 24 minute discussion)

As seen in Figure 4.9, Ms. B's students typically answered one another's questions without attempting to reconcile the disagreements implicit within the question and answer exchange in the majority of their challenging episodes. This was the only class to do so. Moreover, this relatively high frequency of answered challenges is consistent with the questioners asking questions more often than they evaluated and contradicted presentations. That is, as discussed in Section 4.3.3, these Challenging Episodes were framed as requests for more information rather than as statements of disagreement. As such, these questions did not acknowledge that the questioning students and presenters had conflicting understandings of the situation. Without acknowledging these differences, students had no need to reconcile them. Instead, presenters answered the questions and the discussion continued. Moreover, that the audience accepted these answers without further discussion means that their discourse provided no evidence of the audience members attempting to change the presenters' minds. Instead, the discourse patterns of this class are consistent with a discussion in which individuals are attempting to make sure they understood one another's arguments, but not trying to align their contradictory understandings.

Figure 4.9 also shows that these students never reconciled their different interpretations by revising a claim or justification. In other words, these students rarely accepted one another's new evidence in order to collaboratively construct an explanation that accounted for all of the evidence. This lack of revision is consistent with the earlier depiction of the Challenging Episodes as being opportunities for clarification and additional justifications but not for explicit disagreement.

This interpretation of the ways in which students engaged with sensemaking is supported by the final exchange of this Whole Class Debate.[18] In this exchange, one student asked his classmates whether they believed they were all working with the same model and needed to reconcile their different opinions. The class unanimously agreed that they were working with different models and therefore did not need to reconcile their differences.[19] Transcript 4.12 provides an excerpt of this exchange.

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[18] This is actually coded as being part of the Wrap-up discussion because it is the beginning of a whole class discussion in which the teacher leads the students in a post-mortem of the Whole Class Debate. This means that these utterances were not used in the analyses presented in this chapter. However, it immediately follows the Whole Class Debate, with no explicit transition and indicates the students' goals regarding the Debate. I therefore discuss it here.

[19] It is important to note that, in many ways, this exchange mirrors Joshua's question regarding how to reconcile all the different pieces of evidence in Mr. S' class (seen in Transcript 6). However, they are different in the aspects to which they attend in two ways. First, Joshua was confused because he was trying to reconcile the different pieces of evidence in order to form a single explanation. This indicates that he was trying to engage in *collaborative sensemaking* by revising his understanding in light of his classmates' arguments. Toby and his class, on the other hand, were trying to determine whether each group's argument could be true. Thus, Toby's question implies more focus on *making sense of individual arguments* without *collaborative*

1	Toby	Do you guys personally think that the invader that you saw was different from all the different groups' invasive species?	Questioning
2	Student	Yea	Claiming
3	Students	Because it seemed that everyone else's evidence was different from everybody elses'.	Justifying
4	Toby	Right and everyone's evidence seemed evident enough to prove their statements.	Justifying
5	Toby	So that is what you guys believe?	Non-argumentative
6	Students	Yea	Evaluating

Transcript 4.12: Excerpt of class discussion regarding different understandings

This exchange indicates that the students in this class had made sense of one another's individual arguments; they determined that each argument was sound and supported. However, these students treated each argument as unique entities that did not need to be compared with the other arguments. Thus, their classroom discourse did not provide evidence of students engaging in the final aspect of sensemaking: revising their understandings in light of their classmates' arguments.

Figure 4.10 compares the framework for understanding argumentative discourse that I have been developing to the ways in which students in Ms. B's 2005 class engaged in this practice. Notice that Figure 10a now unpacks the idea that students must "attend and respond to one another's understandings" into two ways that could occur: comparing and critiquing

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sensemaking. In addition, Brandon's question was not taken up by his class, and is therefore not indicative of the way in which Mr. S' class took up the Whole Class Debate. In contrast, many students in Ms. B's class responded to Toby's question, and they all agreed that they did not need to reconcile across their different arguments. Thus, Toby's question and his classmates' responses indicate that Ms. B's students had *made sense of one another's arguments*, while Brandon's question indicates he was attempting to make sense of the phenomenon, but that his classmates were not engaged with this argumentative aspect.

arguments (as seen in Mr. S' class) and understanding arguments. I have added this final aspect as a result of this analysis of Ms. B's 2005 class. As made clear by the argument in which these students engaged: when attending to one another's ideas, participants must work to understand those arguments. I have labeled this as an aspect of sensemaking because it represents one way that students can "make sense" during argumentative discourse.

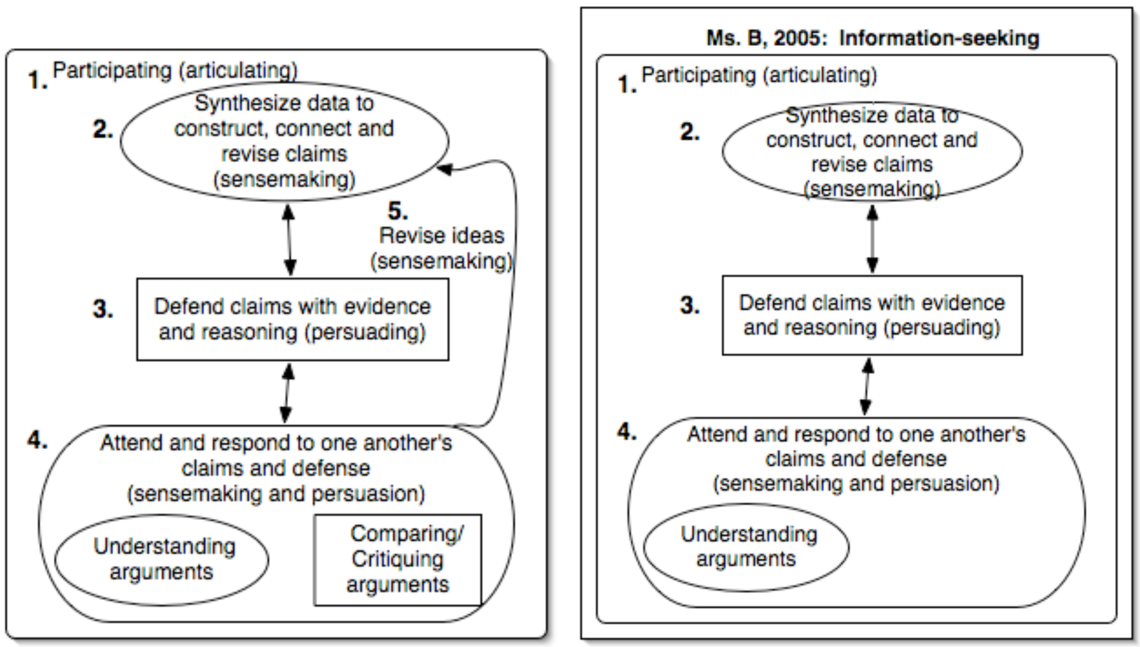

Figure 4.10: Reviewing the definition of argumentative discourse in science classrooms and summarizing the argumentative discourse in Ms. B's 2005 Invasive Species Whole Class Debate

Figure 4.10b indicates that students in Ms. B's 2005 class articulated arguments by participating, engaged in sensemaking (the ovals) by using data to construct their initial arguments and making sense of one another's arguments; and persuaded by defending their claims. However, when compared to Figure 4.10a, it becomes clear that students in Ms. B's 2005 class did not engage in each of the aspects of argumentation. In particular, these students neither compared and critiqued one another's arguments nor learned from one another's arguments in order to revise their initial understandings.

These discourse patterns are consistent with Walton's argumentative dialogue termed "information-seeking," or a "verbal exchange between two parties, one of whom has specific information that the other party wants or needs" (Walton, 1998, p. 127). That is, in these exchanges the questioners were asking neutral questions designed to extract more information from the presenters. In this way, questioners and observers learned what the presenters thought the invader ate through the discourse in this class—the questioners sought information from the presenters.

The three classes analyzed thus far have revealed three different patterns in students' argumentative discourse: arguing as information-sharing, arguing as critical dialogue and arguing as information-seeking. While the last two patterns represent a break from traditional classroom discourse in that the students are substantively paying attention to one another's ideas and discussing the alignment between claims and justifications, none of these patterns show evidence of students engaging in the final aspect of argumentation: revising their ideas in light of one another's arguments. The final class in this data set, Ms. W's class, shows students revising their understandings through the argumentative discourse. I explore this class in the following section.

4.5 Ms. W

As discussed in Chapter 3, Ms. W's class discussions indicated that she highly valued student ideas in that they frequently deviated from the expected path, in order to accommodate student thinking. As a result of these in-depth conversations, Ms. W's class only completed about 8[20] of the 18 lessons in the unit. Thus, I was unable to observe this class engage in the Argument Jigsaw and Whole Class Debate activity structures described in Chapter 3: they did not enact lessons that utilized these activity structures. However, I did observe this class engage in two teacher-led discussions that used two of the three strategies employed by the Invasive Species Whole Class Debate to foster scientific argumentation (these strategies are discussed in more detail in Chapter 3): 1) the problems students investigate had multiple plausible answers so they had something about which to argue substantively and 2) students were given access to rich data sets that they could use to resolve the dispute. In the first discussion, students discussed their observations of microscopic organisms in order to determine whether they were living things. This discussion required that students address sub-questions regarding the characteristics of living things (e.g., if all living things movement then does observation of the microscopic thing moving mean it is living?). Secondly, students used evidence that was presented in the curricular materials to determine what plants need to survive. The purpose of this lesson was for students to confront a common misconception among middle school students—the lesson was designed to help students to realize that plants need water and sunlight to survive but that they can thrive without access to soil. This class demonstrated similar discourse patterns across the two lessons and I use both of these discussions to illustrate the argumentative discourse that emerged in Ms. W's class.

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[20] Ms. W's enactment of the lessons differed greatly from the lesson design – for example she frequently combined discussions from two different lessons or added new discussions – and it is therefore difficult to identify exactly which lessons she did. In the end, her class discussed almost all of the content addressed in the first eight lessons of this unit.

Many students entered this conversation believing that plants needed soil. Ms. W encouraged them to reconsider this claim in light of the available evidence, saying things such as:

> Right now, we are looking at a new set of evidence and if we are scientists we are constantly looking at evidence to see if our ideas are true or not true. So find the evidence… Find the evidence up here in this experiment to support your argument (Observation 13A).

Other than one student's evidence that "you have to plant the seed [in soil]," there was little to defend this erroneous claim. Thus, when asked for support, students often fell silent. For example, early in this discussion Kevin and Patrick correctly interpreted the data in order to provide evidence of plants growing without soil. As Patrick said:

> I said that even though Group 5 had water, light and soil and Group 6 had water and light they both, well Group 6 has more growth.

In other words, in this data set, the plants that had no soil actually showed more growth than the plants with soil. About fifteen minutes after Patrick made this point, Alisha asked whether plants need soil. This question apparently emerged out of the conflict between Alisha's prior understanding that plants need soil to grow and the evidence of them thriving without soil. Transcript 4.13 illustrates how Ms. W handled this and similar questions throughout this discussion.

1	Alisha	Do plants always need soil to grow?	Questioning
2	Student	Yup	Claim
3	Teacher	What does your evidence tell you?	Criteria
4	Alisha	Inaudible	
5	Teacher	Point to…now we heard Kevin give a really explanation. We heard Patrick bring up a really good point.	Crediting author
6	Teacher	So, if you say the evidence up here shows us that we have to have soil, show me that evidence. Just show me the evidence.	Criteria

7	Alisha	[silent]	
8	Teacher	Okay, keep looking. And if you find evidence that shows that that plant can grow, let me know. Okay?	Non-argumentative
9	Brandon	[raises hand]	
10	Teacher	Okay, Brandon?	Non-argumentative

Transcript 4.13: A typical exchange during Ms. W's class' argumentative discussion

In response to Alisha's question Ms. W alluded to her classmate's evidence—or "really good point[s]" –and asked Alisha to provide evidence that plants need soil to survive. Alisha is unable to provide this evidence and falls silent. Ms. W then moved on to the next student, leaving Alisha to work through her conflict between her prior-understandings and the evidence. Beyond illustrating Ms. W's use of the argument structure to facilitate student understandings and the students' silent response to this request, Transcript 4.13 reveals that other students shared Alisha's confusion: notice that in Line 2 an unidentified student agreed that plants need soil to grow.

In the following analysis, I combine data from both argumentative discussions that this class enacted in order to illustrate the ways in which this class engaged in argumentation. In keeping with the framework presented in Chapter 1, I organize this discussion around the three aspects of scientific argumentation: articulation, persuasion and sensemaking.

4.5.1 Articulation

As I did with the other three classes in this study, I assess the degree to which students engaged in articulating arguments by focusing on the frequency with which they made contributions that served argumentative functions. Looking across the two discussions that were designed to support argumentative discourse reveals that students were only making about 5 argumentative contributions every three minutes. As seen in Table 4.2, this is a lower rate of argumentative contributions than any other class. This relatively low rate of participation suggests that the argumentative discussions in Ms. W's class were, in some ways, "less argumentative" than were the Whole Class Debates analyzed for the other three classes.

To a large degree this makes sense: the teachers played a much less active role in the Whole Class Debates than did Ms. W in her class' arguments. Comparing Transcript 4.13 to 4.5 highlights this difference. In Transcript 4.13, Ms. W made 3 argumentative contributions in the space of 10 lines of discourse. In contrast, Transcript 4.5 shows Mr. S making zero argumentative contributions in 11 lines of discourse. By not taking an active role, Mr. S and Ms. B enabled students to question and evaluate one another's ideas during the Whole Class Debates. Similarly, when leading the discussion, Ms. W had more opportunities to quickly evaluate ideas according to the scientific norm, thereby limiting the possibility that the student contributions would play this roll. In other words, the teacher's active role limited the students' opportunities to contribute utterances that fulfilled argumentative functions—it limited their opportunity to articulate.

Ms. W's students did not articulate arguments as much as students in other classes did. That said, they were clearly making contributions that served argumentative functions. Moreover, while the students in the argumentative discussions analyzed in earlier sections argued in the context of student-led presentations and discussions, Ms. W's students made argumentative contributions in the process of a whole class discussion—they made argumentative contributions in response to questions and ideas instead of as a formal presentation. The different context in which the student contributions were made creates an opportunity for a pattern of argumentation not seen in the other classes. Thus, even with this relatively low rate of articulation, I analyze the argumentative discourse in Ms. W's class in order to investigate how students argued when engaged in a teacher-led discussion. In the following sections I explore the ways in which Ms. W's students adopted and adapted the persuasive and sensemaking goals of scientific argumentation.

4.5.2 Persuasion

As I did for the classes that enacted the Invasive Species Whole Class Debate, I examine how students in Ms. W's class engaged in persuasion by exploring the two underlying aspects of this goal: defending ideas and attending to one another's ideas.

4.5.2.1 WHEN AND HOW DO THESE STUDENTS DEFEND THEIR IDEAS?

Students in Ms. W's justified about 58% of their ideas during the argumentative discussions (23 justified ideas out of 40 ideas). Comparing this to the other classes (as seen in Table 4.2) reveals that these students were as likely to justify their ideas as were students in the other three classrooms. In order to more fully understand this comparison, I examine the contexts in which students were justifying their ideas—when and how did students make justifying statements?

Combining the functional analysis with the episodes in which the utterances were made reveals that all but 1 of the students' justifying utterances occurred during a Challenging Episode (when a claim was being questioned, by a student or the teacher) or a teacher-questioning episode (in which the teacher controlled the discussion by asking questions). In other words, almost all of the students' justifications were made in response to a question or challenge.

I use the following three transcripts to exemplify the context in which students justified their ideas. These transcripts are part of a discussion in which the class was determining whether the microscopic things they observed were living things. Before the exchange presented by Transcript 4.14, Matthew shared his data with the class: he observed the microscopic thing moving. In Line 1 of Transcript 4.14, Ms. W asks Matthew to use that data to make an inference regarding the question at hand: was the microscopic thing living?

1	Teacher	Okay, what inference might we make then?	Questioning
2	Matthew	That it is living?	Claiming
3	Teacher	Because?	Questioning
4	Matthew	It moved.	Justifying

Transcript 4.14: Example of a justification during a teacher-questioning dialogue

In Line 3, Ms. W asked Matthew to defend his claim that the thing he observed was living. Matthew complied by repeating his observation that it moved. I explore the implications of this repetition in my discussion of the ways in which this class engaged in sensemaking. For now, I use this exchange as an example of a student offering a justification during a teacher-questioning episode. Approximately half of the students' justifications were contributed in exchanges such as this in which Ms. W encouraged them to defend their claims (19 out of 37).

Ms. W frequently followed exchanges such as the one shown in Transcript 4.14 by asking the rest of the class to respond to the ideas being discussed—to state whether they agreed or disagreed and to support their positions. As shown in Transcript 4.15, she responded to Matthew's claim in a similar way. In this exchange Patrick presented an alternative interpretation of Matthew's data: rather than the movement indicating life, the movement Matthew observed could have occurred because something else moved the microscopic thing.

1	Teacher	What does everyone else think? What does everyone else think?	Questioning
2	Teacher	Patrick	Non-argumentative
3	Patrick	I think that like just because, like say just because, like say it is [inaudible] is moving it.	Justifying
4	Patrick	That doesn't mean it is alive.	Evaluating
5	Teacher	So what might've—but it is hard to get our fingers in that little well and move something. What might have moved it?	Questioning
6	Patrick	Either the air, or like, the water might move.	Justifying

Transcript 4.15: Example of a justification that challenges a claim

I have coded the episode that begins with Transcript 4.15 as a Challenging Episode because Matthew's idea is being challenged with a conflicting inference. The exchange shown in Transcript 4.15 began with Ms. W explicitly asking her students to respond to Matthew's ideas. I explore the implications of her focus on student-to-student interactions in the following section. In this discussion, I focus on Patrick's argument: he has negatively evaluated Matthew's claim that the thing he observed was living by presenting contradictory inferences and justifications—it may not have moved on its own (Lines 3, 4 and 6 in Transcript 4.15).

After Patrick presented this possibility, Ms. W justified the possibility further. As shown in Transcript 4.16, she did this by referring to Matthew's earlier statement that his group members were moving around, and asking whether the group members could have bumped Matthew's microscope (or table) while he was making his observations. Transcript 4.16 shows that Matthew disagreed with this possibility and justified his negative evaluation by offering a new piece of information: his group members could not have bumped the table because they were far away when he made his observations.

1	Teacher	They were talking loud. They were playing around. Maybe the table was bumped. So, maybe it didn't move on its own	Justifying
2	Matthew	They, they	Non-argumentative
3	Teacher	Matthew?	Non-argumentative
4	Matthew	They were like away from the table.	Justifying
5	Teacher	But even so, if I. There is a glass of water on the table and I start moving on the floor, does the water move sometimes?	Justifying
6	Students	Yes	Evaluating
7	Teacher	Okay, so we don't [have] evidence [to resolve this].	Uncodeable
8	Teacher	I think that your inference is really good. You might've had a living thing there.	Evaluating
9	Teacher	But I would say, we had the. That is why I kept telling everyone 'try not lean on the table, because any slight movement, it is a little drop of water we're looking at, can shake it.'	Non-argumentative
10	Teacher	So, they're pretty sure. Their inference is that they saw a living thing.	Criteria
11	Teacher	I kind of agree, except I have this other evidence that says 'maybe somebody shook the table…'	Criteria

Transcript 4.16: Example of a student justifying a claim in response to a challenge

Line 4 in transcript 4.16 is an example a student offering an additional justification in response to a challenge to his or her claim. After Matthew's contribution, Ms. W continued to challenge Matthew' claim—she offered an observation (based on students' experiences) that was counter evidence to his claim (i.e., the students' experiences of small shakes moving water could invalidate Matthew' argument that his group members could not have caused the thing he observed to move), and wrapped-up the episode by acknowledging their disagreement, stating that it was impossible to choose between the two possible interpretations of Matthew's data (i.e., that the movement indicated life or that the movement occurred when the observation was disrupted).

Combining Transcripts 4.14 through 4.16 illustrates that students in Ms. W's class seemed to justify their claims when enabled by the teacher—when the teacher either gave them the floor to do so or explicitly requested a justification. As seen in the these transcripts, the students rarely spontaneously justified their claims but did so in response to a teacher prompt frequently. This is consistent with the early finding that over half of the students' justifications were made in the context of a teacher questioning dialogue. Similarly, Ms. W controlled when students did not justify their ideas as well. There were three different contexts in which Ms. W's students were likely to state unjustified ideas:

1. They made a claim regarding a topic Ms. W is not ready to discuss
2. Ms. W asked a question and then justified the students' response for them—in which case the claim was justified, but not by the students.
3. And, students interjected claims while the teacher was discussing another students' contribution.

In each of these situations Ms. W influenced her students' argumentation—she both created opportunities for them to justify their ideas (as seen in Transcripts 4.14 through 4.16) and limits their ability to justify their ideas. Thus, it appears that Ms. W largely controlled whether and how much her students justified their ideas.

Given this analysis, it appears that these students were able present arguments that were constructed in a persuasive manner—they were as likely to justify their ideas as were the students in the other three classes analyzed. However, that the teacher frequently elicited their justifications may indicate that these students were less engaged with this aspect of scientific argumentation than were students in the Whole Class Debates.

4.5.2.2 How does the audience attend to one another's ideas?

In the analyses of the other three class' argumentative discourse, I explored whether and how students attended to one another's ideas in order to assess their engagement with this aspect of persuasion. However, Ms. W was leading the discussions that occurred in her class and there were consequently many fewer student-to-student interactions.

Ms. W's role in the argumentative discussions is made apparent in Figure 4.11 that reveals the context in which students made substantive contributions. As seen in this figure, half of all student contributions were elicited by an explicit teacher prompt. As seen in Table 4.4, this is substantially more than the percentage of teacher prompts that were found during the Whole Class Debates: of the three classes that engaged in Whole Class Debates, Ms. B elicited the most student contributions in 2006, when she elicited about 38% of the students' contributions. This comparison underscores the difference between these activity structures: in the design of the activity, the teacher's role was outlined as much more prominent in the teacher-led arguments than Whole Class Debate.

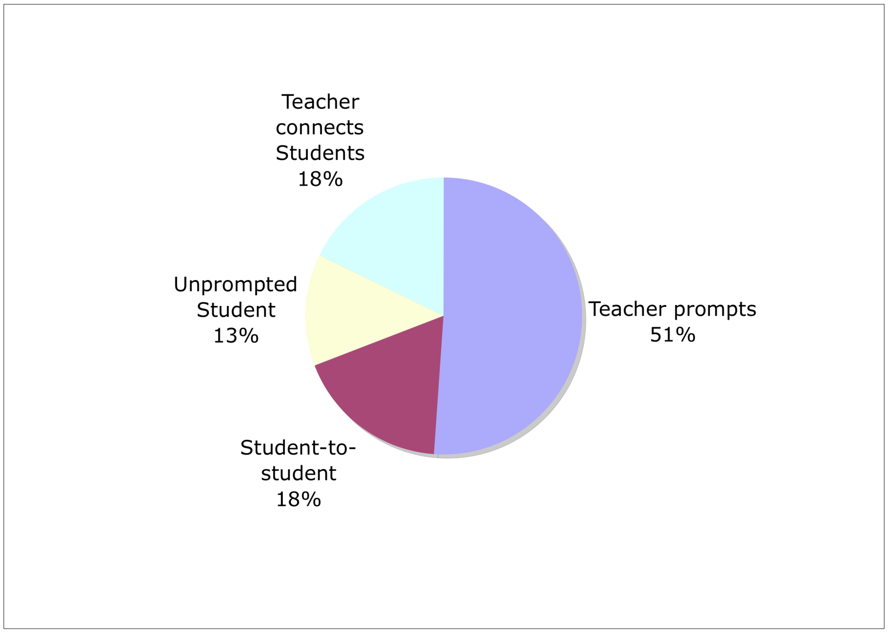

Figure 4.11: Interactions that elicit student contributions in Ms. W's argumentative discussions

(N = 84, taken from 69 minutes of discussion)

The relatively low frequency of student-to-student interactions that occurred in these discussions (15 out of 84) indicates that these students were not directly responding to one another's arguments. However, I do not take this to mean that these students failed to attend to one another's ideas: the interactions in which Ms. W explicitly asked students to respond to one another (teacher connects students) were instances in which students were attending to one another. For example, in Transcript 4.15, Patrick evaluates Matthew's argument in response to Ms. W's prompt—this is therefore coded as an instance of the teacher connecting the students, but it is clearly an instance in which a student has explicitly listened to and evaluated his classmate's idea. Moreover, students often responded to Ms. W by evaluating her arguments. For example, in Line 4 of Transcript 4.16, Matthew counter-justified Ms. W's argument. In both of these examples students responded to the ideas being discussed, thereby indicating that they were attending to these ideas.

The analysis of interactions indicates that these students did not engage with one another's ideas as explicitly as students did in the other three classes. However, evidence from the classroom discussions indicates that they were responding to the ideas being discussed more than Figure 4.11 may imply. Figure 4.12 examines the relative frequencies with which student contributions fulfilled the functions necessary for argumentative discourse in order to directly examine the frequency with which students were responding to the ideas discussed.

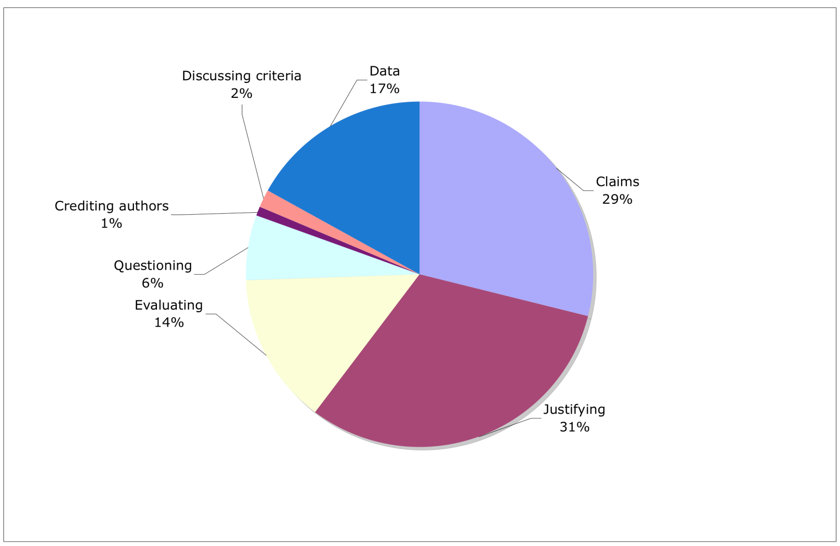

Figure 4.12: Function of student utterances in Ms. W's teacher-led argumentative discussions

(N = 118, taken from 69 minutes of discussion)

As seen in Figure 4.12, approximately 20% (or 24 of the 118 student utterances) in this class were an explicit response to an idea being presented (17 were an evaluation and 7 were a question). In the other three classes analyzed, Ms. B's 2006 had the lowest rate of students responding to an idea: about 29% of their utterances were evaluations or questions (shown in

Table 4.5). This indicates that—regardless of whether the ideas discussed were authored by the teacher or peers—students in Ms. W's class were not responding to the ideas of others as frequently as were students that engaged in the Whole Class Debate. That is, it appears that the Ms. W's students responded to one another's ideas less than students in the other three classes did.

Examining the instances in which Ms. W's students did explicitly respond to ideas shows that these students were more than twice as likely to evaluate an idea as they were to question it. This ratio is similar to that of Mr. S' class. In Mr. S' case, I argued that the emphasis on evaluation over questioning may indicate that the students were attending to the persuasive goal of scientific argumentation because they were stating whether they are persuaded of the ideas discussed. The ratios and statistics allow a similar claim to be made for Ms. W's class, however I only do this cautiously as the students only made 17 evaluative comments overall, whereas they made 37 in Mr. S' class.

Combining across these two analyses provides evidence of the students attending to some aspects of persuasion, but not all. In particular, they structured their arguments in a way that suggested attention to the goal of persuasion by defending them when this behavior was enabled and/or requested by the teacher. However, they responded to the ideas being discussed less frequently than students did in the other contexts. When students did respond to the differing ideas, they were likely to state whether they were persuaded by these ideas—to evaluate them. In the following section I explore how the students' less frequent response to one another's ideas affected their adaptation of the sensemaking goal.

4.5.3 Sensemaking

When discussing the ways in which students engaged in sensemaking in the previous three analyses, I highlighted three aspects of sensemaking: 1) constructing initial claims 2) making sense of the arguments being discussed and 3) revising claims in light of contradictory or new evidence and arguments. In the following sections I explore first whether and how students made sense of one another's arguments and I then move on to a discussion of the first and third aspects of this goal: how did students in this class construct and revise their claims?

4.5.3.1 Making sense of one another's arguments

As seen in Table 4.4, students in Ms. W's class were less likely to respond to one another's ideas than were students in the other three classes (only 18% of the interactions involved a student responding to another, in Ms. W's class while Ms. B's 2006 students, the ones closest to Ms. W on this variable, responded to one another in 38% of their interactions). Moreover, when they did so, they asked about half as many questions as they made evaluative comments. In other words, they were twice as likely to state whether they agreed with an argument as they were to ask questions in order to learn more about and understand an argument. In this way, it appears that they clearly made sense of the arguments discussed—they had to in order to evaluate them. However, given the emphasis on evaluations over questions and that the teacher prompted the majority of these responses, it appears that students did not emphasize this aspect of sensemaking. In other words, they made sense of one another when prompted to do so, but unlike Ms. B's 2005 class in which the students focused on this aspect of argumentation, the discourse in Ms. W's class aligns with one in which making sense of one another is not an explicit goal.

4.5.3.2 Constructing and revising claims

While it appears that making sense of competing arguments was not emphasized in these discussions, there is evidence that these students did engage in a synthetic form of sensemaking in which they were synthesizing evidence and arguments in order to construct and revise claims that best fit the available data. I illustrate this emphasis on synthesizing data, and support my claims regarding the students' emphasis in this class, in two ways: first by examining patterns in the discourse and second by turning to students' post-interviews.

4.5.3.2.1 Students' synthetic discourse

Recall Transcript 4.14 in which Ms. W and Matthew discuss Matthew's observation of something moving under the microscope. When Matthew first shared this observation he was reporting his data. Ms. W then asked Matthew to interpret that data—to make a claim—and to defend that claim. He defended his claim by restating his observation that he observed the microscopic thing moving. This repetition underscores the changing role of the observation: it started out as data that needed to be interpreted and it became evidence to support a claim. Ms. W's class was the only one of the four classes analyzed in which data played a prominent role before it was harnessed as a justification for a claim (as seen in Table 4.5, 17%—or 20 out of 118—of the students' argumentative utterances explicitly discussed data without using it to justify a claim). It suggests that students in these discussions may have had a different relationship to the data being discussed then did students in the other classes: it appears that Ms. W's students discussed data in order to synthesize it and construct a claim.

Transcript 4.17 provides an example of how the students and teacher in this class discussed and synthesized data during whole class discussions. In this exchange, they were discussing plants' survival needs. They grounded this discussion in a data table (Figure 4.13) that displayed the results of an experiment in which plants were provided with different combinations of resources (soil, sunlight and water) and observed over a course of 6 weeks (students did not conduct this experiment, in this discussion they are interpreting the data that was provided in the curricular materials).

1	Teacher	What happened at the end of the 4th week with the plants that had everything?	Questioning
2	Teacher	Kevin?	Non-argumentative
3	Kevin	It is still growing. Green. All plants have new leaves. Average growth is 1 cm.	Data
4	Teacher	Okay. 1 cm. Okay.	Evaluating
5	Teacher	What happened to the plants that had everything but light at the end of the 4th week?	Questioning
6	Teacher	Wafa?	Non-argumentative
<snip, classroom management>			
12	Wafa	Okay. 'Plants are starting to drop. Leaves are yellow and pale on all the plants.'	Data
13	Student	Droop	Non-argumentative
14	Teacher	‘Plants are starting to droop. Leaves are yellow and pale on all the plants'	Non-argumentative
15	Teacher	What is this giving us evidence of? What can we say about these plants? Christina?	Questioning
16	Christina	That plant right there is dying.	Claiming
17	Teacher	It seems to be dying. Not doing as well. We don't see any new growth. We see that nice green color going away. It just doesn't look like a healthy plant. Good.	Justifying

Transcript 4.17: Example discussion around interpretation of data

PLANT GROUP	WATER	LIGHT	SOIL	RESULTS WEEEK 1	RESULTS WEEK 4
1	X		X	Plants are still growing, not as green as they was a week ago	Some plants have yellow leaves, no new growth
2	X	X		Growing, green leaves, new leaves starting to form	Still growing, green, all plants have new leaves, average growth is 1cm
3		X	X	Plants are starting to droop, leaves are still green	Leaves turning brown, some plants falling over

Figure 4.13: Excerpt from the class' data table used to determine the resources plants need to survive

Notice that in Lines 1 and 5, Ms. W prompted her students to state the data. For example, in Line 12, Wafa reported that in the fourth week, plants that did not have sunlight were turning yellow and drooping. Ms. W then asks Wafa to interpret that data—to make a claim regarding what the data could mean. Christina replies to this request by offering the claim that the plants without sunlight were dying (Line 16).

Ms. W and her class moved through each plant group in the table, making claims regarding whether the plants were surviving under each of the conditions, in a manner similar to the excerpt presented in Transcript 4.17. Throughout this discussion, Ms. W pushed her students to think about the larger question: what do plants need to survive. As such, these sub-claims—these interpretations of the data—became evidence to support their claims regarding whether plants could survive without soil. In this way, Ms. W guided her students as they made sense of the data in order to construct claims that could be defended. This illustrates a synthetic form of sensemaking: the students and teacher in this class were engaged in making and revising claims by synthesizing the data and possible claims in order to identify one claim that best explained the data.

Shortly after the exchange shown in Transcript 4.17 Alisha asked whether plants needed soil. The discussion that followed this question is shown in Transcript 4.13 and is apparently motivated by Alisha 's disagreement with the claim being sanctioned in the class discussion (i.e., plants can live without soil). Recall that Ms. W answered the question by reminding Alisha of her classmates' evidence of the plants without soil growing and encouraging her to find evidence that could support her claim that plants must have soil to grow. Alisha responded to this prompt with silence. While it is difficult to determine whether this silence meant that Alisha revised her original claim in light of her teacher's argument a post-interview indicates that she was struggling with integrating the data discussed in the class with her own understandings. In this interview, Alisha reported that she started out thinking plants could live *without* soil and changed her mind through the discussion; at the time of the interview she defended her claim that plants *needed* soil to survive by saying you have to plant seeds in soil, not water. This interview result is clearly less than ideal—it seems to indicate that the class' work with interpreting data pushed Alisha to change from an accurate understanding to an inaccurate one. However, accuracy aside, it indicates that Alisha was working to make sense of the contradictory evidence in order to construct a claim that accounted for all of the available information. In the following section, I explore the frequency with which conversations like the one depicted in Transcript 4.17 were paired with students revising their understandings in light of new evidence.

4.5.3.2.2 Evidence of students revising their understandings

In the other classes I examined the degree to which students synthesized across their different understandings and the data by focusing on the conclusion of the Challenging Episodes: how often did participants reconcile their differences through revision? This analysis is less useful in Ms. W's class because the conversation was teacher-led; Ms. W was trying to convince her students of scientific ideas and, as a result, the majority of the Challenging Episodes concluded with Ms. W determined that the students had revised their erroneous understandings, regardless of whether that revision was made explicit. Thus, I do not look to the Challenging Episodes in this class for evidence of students' revising their understandings in light of contradictory or new evidence and arguments. Instead, I look for the students' final understandings to either differ from their original understandings or (as I do not always know the students' original understandings), to be scientifically accurate and explicitly based in evidence discussed in class.

At the conclusion of the discussion regarding plants' needs three students defended the claim that plants can live without soil. Kevin and Patrick did this by referring to the experimental data showing that plants could grow without soil. Bryon, on the other hand, introduced his own experiences, talking about his observations of plants growing out of cement. In post-interviews we asked five students[21] what their original claims were regarding plants and soil and to defend their final understandings. Four of these students show evidence of revision in that they either changed their claim or were able to defend their final claim with evidence that was discussed in the classroom.

Combining the analysis of students' arguments during the class discussion and post-interviews reveals that Ms. W's insistence that the students support their claims with evidence—that they construct an argument for their claims—facilitated their evaluation and potential revision of their claims. That is, the task of *articulating* an argument seemed to support students in *constructing* and *revising* their claims.

4.5.3.3 Characterizing the argumentative discourse in Ms. W's class

The earlier discussion of the ways in which students in Ms. W's class engaged in sensemaking depicts classroom discussions in which claims are being constructed—the students

[21] We conducted these post-interviews with our eight focus students but only five were in class during the plant/soil discussion. Consequently, we only have five data points for this specific discussion.

and teacher are interpreting and synthesizing data in order to construct claims that align with that data. These discussions were less like a prototypical argument in which individuals debated contradictory arguments then they were similar to a traditional whole class discussion in which the teacher guided students' knowledge building. This comparison raises the question: in what ways is the sensemaking seen in Ms. W's class the type of sensemaking discussed in the literature on scientific argumentation, and defined in Chapter 1?

I address this question by comparing my characterization of the argumentation that occurred in Ms. W's class to the aspects of argumentation identified in the literature and developed through the analyses presented in this chapter. Figure 4.14 illustrates this comparison.

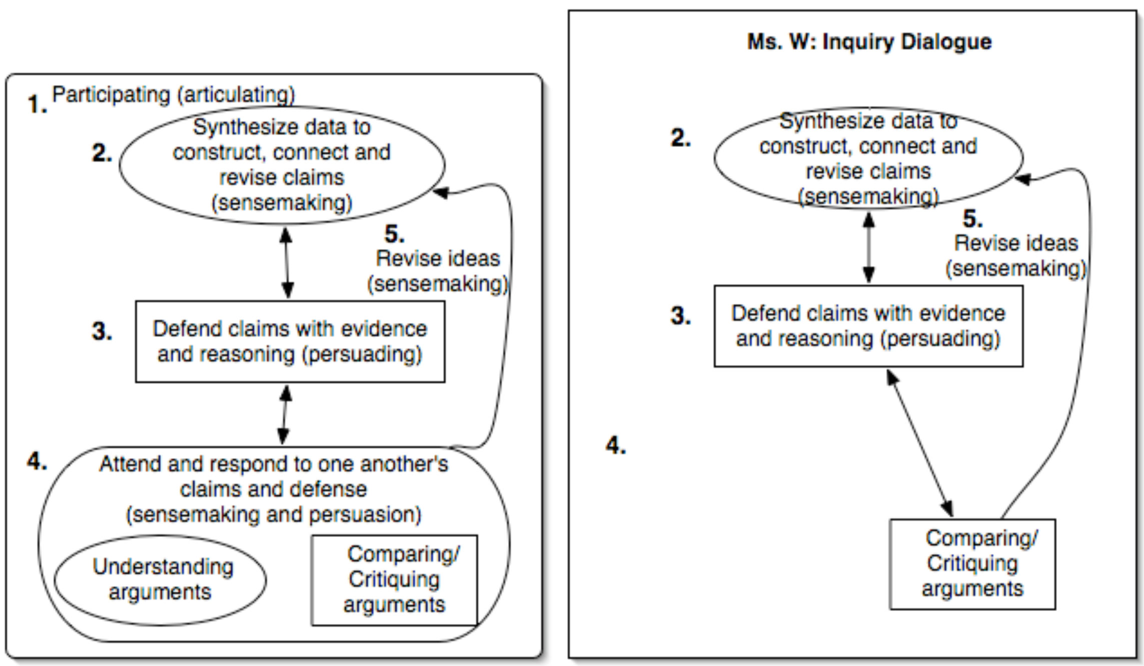

Figure 4.14: Reviewing the definition of argumentative discourse in science classrooms and summarizing the argumentative discourse in Ms. W's whole class discussions

Examining Figure 4.14 reveals that students in Ms. W's class engaged in a style of argumentation that was very different from both the argumentation that occurred in the other classes and the prototypical form represented in Figure 4.14a. First, while Ms. W's students would evaluate a classmate's idea in response to a teacher prompt, they rarely responded to a classmate's idea spontaneously. Consequently, the students in this class appeared to interpret the argumentative task as one of listening and responding to the teacher but not necessarily one of listening and responding to one another's ideas. I therefore have characterized their argumentation as one in which participants were not attending to one another's ideas. However, the frequency with which they evaluated one another's arguments—at Ms. W's prompting—is consistent with a discussion in which students compared and critiqued one another's arguments (e.g., they compared their own understandings and the available evidence to other possible claims in order to evaluate them). Hence, Figure 4.14 shows that the students did not attend to one another's ideas, but they did compare and critique them. This apparent contradiction illustrates the finding that these students only evaluated the ideas being discussed when asked to do so.

In addition, as discussed in the previous analyses and shown in Figure 4.14, these students constructed claims and defended them. Moreover, this class was the only one in which students revised their claims in light of the evidence being discussed—seen in the arrow connecting Aspects 4 and 1 on Figure 14.4.

Comparing this characterization of Ms. W's students' argumentation to the arguments in the other three classes reveals that Ms. W's students engaged in a unique combination of the aspects of argumentative discourse. That is, similar to Mr. S' class, these students compared their arguments by stating whether they were persuaded by them. However, Ms. W's students moved beyond this by using evidence to reconcile their prior-understandings with her own claims. This combination—this comparing and revising of arguments—is consistent with a discussion in which the participants engaged in sensemaking (by constructing and revising claims) and persuasion (by defending claims and comparing their own ideas to contradictory claims and evidence).

I am not suggesting that Ms. W's students were the only students to engage in sensemaking by synthesizing the data. Students in the other classes clearly synthesized data in order to construct the claims that they defended, evaluated and questioned. However, students in these classes did not respond to one another's ideas by considering a revision of their own. This indicates that these students were not engaged in this form of sensemaking. Ms. W's students, on the other hand, responded to contradictory claims and evidence by incorporating the convincing arguments into their developing understandings.

The emphasis seen in Ms. W's class on constructing, defending, comparing and revising arguments aligns with what Walton calls an "inquiry" dialogue. He describes this dialogue as

> a group of people get[ting] together to collect and organize all the relevant evidence on some particular proposition, both for and against. They then assemble and organize this evidence, drawing out conclusions in an orderly fashion so that each conclusion can be definitely proved (Walton, 1984, p. 69).

Ms. W's students engaged in this dialogue when they compared their claims to the available data and revised those understandings in light of the contradictory evidence.

4.6 DISCUSSION

The analysis presented in this chapter explored how individual classes adopted and adapted the practice of scientific argumentation in terms of the goals of articulation, persuading and sensemaking. In this discussion, I explore the implications of this analysis in terms of three outcomes:

1. the expansion of the characteristics of argumentative discourse;
2. the coherency of each of the adaptations of scientific argumentation exhibited by the participating classes;
3. and, the implications of these adaptations with respect to student engagement in the goals of argumentation

4.6.1 Expanding the characteristics of argumentative discourse

Figure 4.15 depicts how the analysis presented in this chapter expanded upon the characteristics of argumentative discourse first presented in Chapter 1.

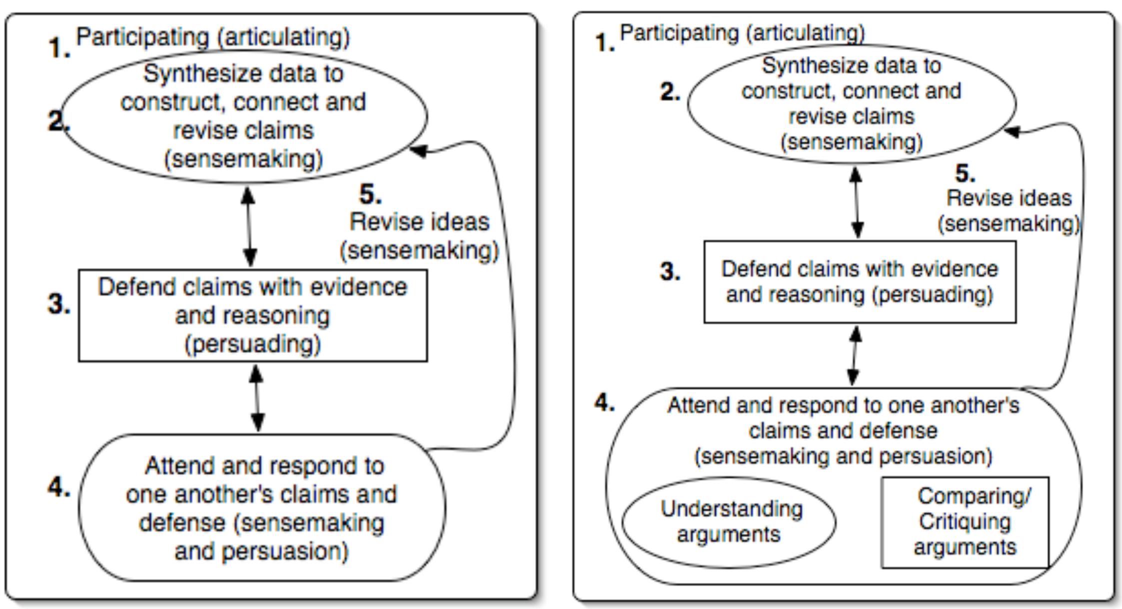

Figure 4.15: Comparing my original analysis of the characteristics of argumentative discourse to the refined version that emerged in this chapter

My analysis of classroom discourse identifies five main characteristics of argumentation:

1. Individuals participating
2. Individuals stating *claims*
3. Individuals *defending* their claims
4. Individuals attending and responding to one another's *claims and defense*
5. Individuals revising their own and other's *claims*

The analyses presented in this chapter have extended the fourth characteristic of this discourse, attending and responding to one another's claims and defense, by identifying the ways in which one might do so. Students in Ms. B's 2005 attended and responded to one another's ideas by treating them as unique entities that they should understand. To that end, they asked one another neutral questions designed to extract more information from the presenters. However, they did not compare their own ideas to those of their classmates; they rarely explicitly stated whether they agreed with their classmates. Consequently, the discourse in this class was consistent with a goal of understanding one another. I have added this to the possible characteristics of argumentative discourse because it highlights one way that students can respond to one another's ideas. Moreover, it highlights a key way that students can attend to sensemaking; they can make sense of one another's arguments without working to reconcile their differences.

In addition to "understanding arguments," these analyses have identified one additional way that students can explicitly attend and respond to one another's ideas: they can compare and critique them. This characteristic is made most apparent in Mr. S' class in which the students frequently and explicitly evaluated whether they agreed with their classmates—they frequently compared their classmates' ideas to their own and to the available evidence. In addition, when they disagreed, these students would critique one another's arguments. I have added this characteristic as one way that students can attend to persuasion because it foregrounds that goal: evaluating whether an idea is persuasive by comparing it to your own idea and the available evidence and critiquing ideas with which you disagree are two ways that individuals can engage in persuasive discourse.

I use this refined framework throughout this discussion to understand the implications of how students in each of the classes adopted and adapted the practice of scientific argumentation. In the following section, I review the ways in which each classroom community engaged in argumentation and I explore the internal coherency of their practice: why do their individual takes on argumentation make sense?

4.6.2 Exploring the coherence of the adaptations of argumentation

The analyses presented in this chapter identify four ways that classroom communities could adapt the aspects of scientific argumentation. Building on Walton's analysis of the different argument types, I have called these adaptations: information-sharing; information-seeking dialogue; critical dialogue; and inquiry dialogue (1998). In this section, I review the ways in which I characterized the argumentative discourse in each class and examine the relationship between each of the aspects of argumentation in which they engaged. Through this analysis, I ask why it made sense for students to show evidence of some aspects of argumentative discourse and not others.

4.6.2.1 Ms. B, 2006: Students engaging in information-sharing

I began by exploring the coherency of the way that students in Ms. B's 2006 class adapted and adopted the practice of scientific argumentation. As discussed in Section 4.2, students in this class engaged in a simplified form of argumentative discourse that I called "information-sharing." In this class, student groups rotated through presentations of their arguments. As depicted in Figure 4.16, these presentations—or opportunities to share—provided evidence of students having constructed claims that aligned with the available evidence (aspect 2) and defended those claims (aspect 3).

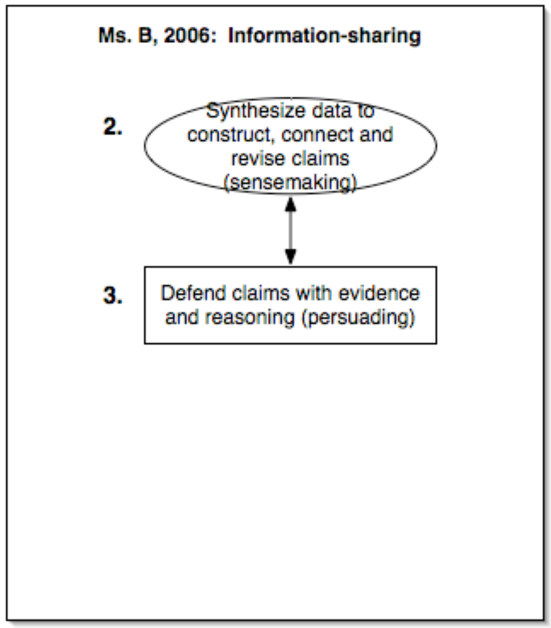

Figure 4.16: Reviewing the characterization of the argumentation in Ms. B's 2006 class

However, as seen in Figure 4.16, students in this class did not go beyond this. In general, students in Ms. B's 2006 class made almost all of their argumentative contributions when presenting their formal arguments and rarely participated in the discussion at other points in time. That is, a single student typically presented his or her argument and made few contributions during the rest of the discussion. This is evident in the low rates of both participation seen in this class (represented in Figure 4.16 by the lack of aspect 1, participation), and student-to-student interactions (seen in Figure 4.16 by the lack of aspect 4, responding to one another's ideas). Thus, these students rarely contributed outside of their formal presentations.

The students' lack of attention to one another's ideas combined with the presentation of their own ideas is consistent with a take on the argumentative activity as being one of information-sharing. That is, these students have accomplished the goal of sharing their own arguments while providing little evidence of attention to other possible goals of the activity (such as persuasion or sensemaking). Moreover, this focus on information sharing is largely consistent with the way in which I characterized traditional classroom norms in Chapters 1 and 3: these students have demonstrated their group's successful completion of the task (construction of an argument that explained the phenomenon under study) without engaging with one another's ideas (e.g. Hatano & Inagaki, 1991; Newton et al., 1999; Scardamalia & Bereiter, 1994; Weiss et al., 2003). Thus, this class appears to be an example of one in which the classroom community adapted the aspects of scientific argumentation to more closely align with the norms of the classroom, rather than transforming the norms of the classroom to fit with this new practice. In Chapter 5, I explore this conclusion by comparing the classroom norms seen in Ms. B's 2006 class to their adaptation of scientific argumentation.

4.6.2.2 Ms. B and Mr. S: Students engaging with one another's ideas

Ms. B's 2005 class and Mr. S' class reveal similar patterns of argumentation: in both cases students were actively participating while they constructed claims; defended claims, and responded to one another's ideas. Figure 4.17 summarizes the analyses of these classes.

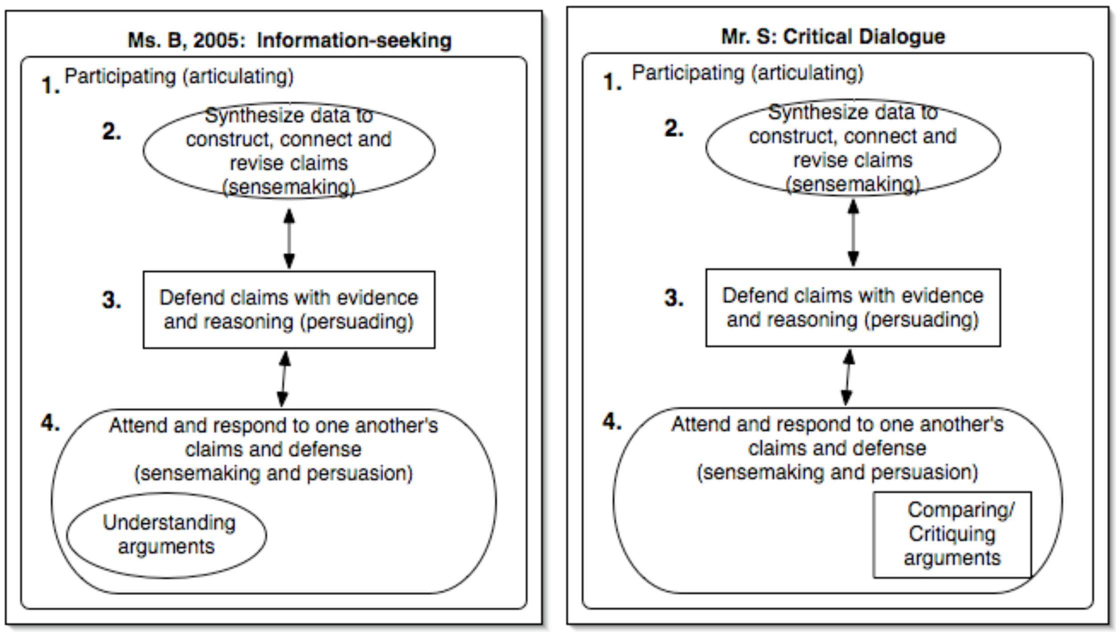

Figure 4.17: Reviewing the characterization of the argumentation in Ms. B's 2005 class and Mr. S' class, the two classes in which students engaged with one another's ideas

In contrast to Ms. B's 2006 class, the students in both her 2005 class and Mr. S' class made argumentative contributions at relatively high rates and attended and responded to one another's arguments. This combination of the aspects of argumentative discourse reveals a shift from the traditional norms of school: rather than speaking to the teacher, students were interacting directly with one another's ideas (e.g. Cazden, 1988; Hatano & Inagaki, 1991; Lemke, 1990; Mehan, 1979). However, as seen in Figure 4.17, Mr. S and Ms. B's 2005 students responded to one another's ideas in different ways: Mr. S' students compared and critiqued one another while Ms. B's 2005 students worked to understand one another. In this section, I compare the sense that each class made of this practice and discuss how each of their unique combinations of discourse characteristics are internally coherent.

The argumentation in Mr. S' class seemed to emphasize the persuasive goal of scientific argumentation: the students in this class compared and critiqued one another's arguments by stating whether they agreed with them and contradicting them, when possible. As discussed in Section 4.3, this version of argumentation is consistent with Walton's "critical dialogue" because it focuses on the goal of persuasion such that the students appeared to be focused on persuading others of the accuracy of their own claims by criticizing those of their classmates (1998). That is, the discourse that emerged in this classroom is consistent with a discussion in which individuals are attempting to disprove one another in order to prove that their own ideas are correct.

Since the goal of persuasion is an individual goal rather than a more collaborative goal of accounting for all of their perspectives, the apparent focus on disproving one another meant that students were not in positions to revise their own understandings in light of their classmate's arguments (aspect 5). That is, while attempting to persuade others, these students did not have a reason to be persuaded themselves. Moreover, had students admitted that a classmate's contradictory argument had strengths they would have been admitting that theirs might have weaknesses. As such, "being persuaded" –or revising their understandings in light of a contradictory argument—may have been counter-productive to the students' apparent goal of persuasion. In this way, the version of argumentation in which Mr. S' students engaged is sensible: not only does persuading some one of an idea (by presenting it and critiquing opposing ideas) not require revising one's own ideas, but these aspects of the discourse may appear to be in conflict. This is consistent with Hogan and Corey's work (2001), in which they found that students were likely to perceive the revision of an understanding as the admission of weakness and, as such, this revision may be contradictory to the traditional classroom goal of demonstrating expertise.

In contrast, Ms. B's 2005 students did not emphasize persuasion. Instead, as seen in Transcript 4.12, these students determined that they were working with different computer models and therefore did not need to acknowledge their differences. Consequently, these students ignored their disagreements and worked to understand each individual argument as a unique entity. In Section 4.4, I characterized this form of argumentation as being similar to Walton's "information-seeking dialogue" in that the students' interactions where consistent with ones in which individuals are attempting to understand one another (1998): these students shared their own ideas (aspects 2 and 3) and then questioned those of their classmates, without attempting to reconcile the differences.

That students in Ms. B's 2005 class ignored their disagreements meant that they were largely unable to revise their understandings in light of their differences. That is, if the students believed that they each had different computer model then they had no reason to compare their understandings and incorporate one another's evidence into their own. Thus, in this class, the focus on seeking information about one another's arguments, without understanding the relationships between the arguments, is consistent with the students' lack of revision: without engaging in this cross group comparisons, students were unable to synthesize their arguments because they were not considering how one argument might affect or relate to another.

Comparing Mr. S' and Ms. B's 2005 classes reveals that the ways in which these students engaged in argumentation emphasized individual performance rather than a collaborative endeavor. That is, the students in both classes found a way to engage in the social interactions of argumentative discourse (attending to, comparing and understanding one another's ideas) without threatening the traditional norms that emphasize individual success in a classroom.

4.6.2.3 Ms. W: Students engaging in an inquiry dialogue

The argumentative discourse that emerged in Ms. W's class differed from the argumentation seen in the other classes. In this class, the students and teacher worked together to synthesize complex data sets and competing understandings of that data. Following Walton's scheme, I termed this form of argumentation an "inquiry dialogue" (1998) because the apparent goal of these interactions was for students to make sense of the phenomenon under study—or conduct an inquiry. In Figure 4.18, I review the aspects of argumentative discourse that these students engaged in as part of their inquiry dialogue.

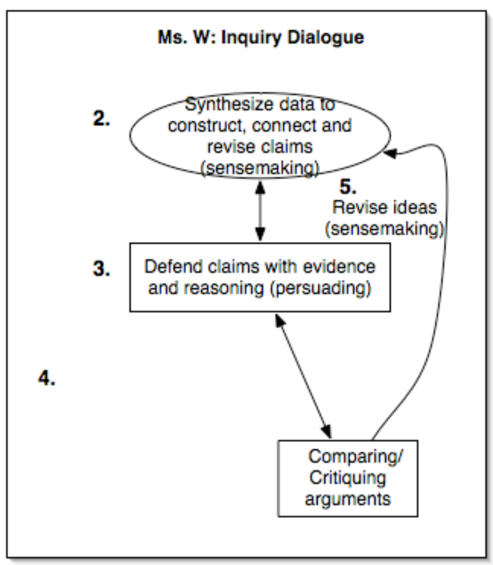

Figure 4.18: Reviewing the characterization of the argumentation in Ms. W's class

My characterization of the argumentative discourse in this class stems largely from the combination of the students constructing and defending claims, comparing and criticizing of competing ideas and then (if necessary) revising their own ideas. That is, these students compared and critiqued alternative interpretations of the evidence relatively frequently. In addition, this was the only class in which students explicitly revised their understandings in light of the class discourse. This combination of discourse characteristics reveals students determining whether the ideas and evidence being discussed indicated that they should revise their own understandings—it reveals the students investigating the evidence and interpretations of that evidence in order to make sense of the phenomenon under study.

In addition, similar to Ms. B's 2006 class, I have characterized the discourse in Ms. W's class as lacking in student participation and student-to-student interactions. This is largely the result of the activity structure in which this class was engaged: they were participating in a teacher-led discussion in which the students responded to questions posed by their teacher through a traditional triadic dialogue (Lemke, 1990). Consequently, the students had fewer opportunities to respond directly to one another's ideas. Instead the comparing and critiquing that they did was typically in the context of a teacher-student interaction. This combination of discourse characteristics indicates students were engaged in inquiry by exploring the evidence and possible interpretations of that evidence.

It may be that the combination of asking students to compare and critique one another's ideas while deemphasizing the importance of student-to-student interactions facilitated the students' revision of their ideas. That is, this combination of discourse characteristics may have helped students focus on alignment between the claims and evidence without getting caught up in the social aspects of directly engaging with one another.

4.6.3 Comparing across the classes

The analyses presented in this chapter, and the discussion thus far, examine the argumentation that occurred in individual classes. This section moves beyond this by focusing on the patterns revealed by focusing on single goals and looking across the classes. That is, in this section, I examine cross-class patterns in how students engaged with the goals of persuasion and sensemaking.[22]

4.6.3.1 WAYS THAT CLASSROOM COMMUNITIES ENGAGE WITH PERSUASION

Other than constructing their initial claims, the only aspect of argumentative discourse that students in all four cases demonstrated was the presentation of arguments constructed in a *persuasive* manner, as seen when the they defended their ideas. Mr. S' class and Ms. B's 2005 class both exhibited this discourse characteristic as part of a larger practice in which the students responded to one another's ideas in a substantive manner. In Ms. W's case, the students did this when it was enabled and supported by the teacher. In 2006, Ms. B's class only constructed and defended their ideas.

That all four cases exhibit student success with this aspect of argumentative discourse raises questions regarding the alignment between this aspect of argumentative discourse and typical classroom interaction patterns. Chapter 5 will focus on this question, addressing the relationship between this aspect of the practice and the students' expectations regarding classroom discourse. For now, the important result is that the defense of ideas is one aspect of argumentative discourse in which students seem to be able to engage in a substantive and real

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[22] I am not discussing the students' adaptations of articulation because my analyses of this goal were one-dimensional: I examined the relative frequency with which students contributed utterances that fulfilled argumentative functions. Thus, while the classes exhibit different degrees of success with this goal, they do not reveal different ways of engaging with it.

manner; it is possible to consistently support students in constructing arguments in which their claims are thoroughly justified.

Moving beyond presenting arguments in a persuasive manner—the defense of ideas—reveals that classes were less consistent with other aspects of persuasion (i.e., attending to one another's ideas and comparing/critiquing ideas). For example, in half of the classes in this study—Mr. S' class and Ms. B's 2005 class—students attended and responded to one another's ideas. However, in only one of those classes did this attention exhibit a focus on persuasion; only in Mr. S' class did the attention to one another's ideas manifest as students determining whether they were persuaded by their classmates' arguments by comparing their own understandings and evidence to those of their classmates. Moreover, in the second class in which students compared across one another's arguments—Ms. W's class –the students did not emphasize the importance of attending to one another's ideas. Thus, Mr. S' class is the only one of four participating classes in which students engaged in all possible aspects of persuasion.

This finding aligns with both my pilot studies (Berland & Reiser, in press; Kuhn, Kenyon, & Reiser, 2006; Kuhn & Reiser, 2006) and other literature regarding ways to foster student engagement with one another's ideas (e.g. Brown & Campione, 1996; Ford & Wargo, 2007; Scardamalia & Bereiter, 1994): students are not typically in situations that encourage them to attend to whether they are persuaded by their classmate's ideas. In Chapter 5, I will examine the existing classroom culture found in Mr. S' room and his teaching strategies, in order to understand how and why these students engaged in this aspect of the practice. I will also explore the existing classroom cultures and teacher strategies of the other classes in order to determine why these aspects of persuasion did not make sense in those contexts.

4.6.3.2 Ways that classroom communities engage with sensemaking

As I did for the analyses of individual class' engagement with sensemaking, I explore student sensemaking in terms of three aspects: 1) construct claims, 2) attending and responding to one another's ideas and 3) revising their understandings in light of the ideas discussed. Combining across these cases reveals that students in all four classes constructed initial claims that were consistent with and could be defended by the available evidence. In addition, students in two of the four classes demonstrate that they are making sense of one another's arguments by either comparing and critiquing them (Mr. S's class) or questioning them (Ms. B's 2005 class). However, in all of the classes in which students engaged in the Invasive Species Whole Class Debate (e.g., Ms. B in 2005 and 2006 and Mr. S), students struggled with revising their understandings in light of one another's ideas and evidence. In other words, students in these classes struggled with using the argumentative context as an opportunity to learn from one another. In Ms. W's class, on the other hand, students revised their ideas during the argumentative discussion relatively frequently.

Examining the differences in how students in each class adapted the practice of scientific argumentation indicates that they had different opportunities and motivation to revise their understandings as a result of the discussion. That is, it appears that the different forms of sensemaking seen in each class are consistent with, and possibly constrained by, the goals of the argumentative activity in which each class engaged. For example, Ms. B's 2006 class, the students' apparent goal was to share their ideas and doing so required that they neither attend to their classmates' ideas nor revise their own. In the previous year, Ms. B's class attended to one another, but they concluded that they all had different questions (i.e., computer models) and therefore did not need to revise their individual thinking in light of everybody else's. Finally, Mr. S' students appeared to focus on the goal of persuasion such that they were successful if they convinced others of the accuracy of their claim, not if their classmate's arguments caused them to revise their own.

In contrast, Ms. W seemed to create an environment in which individual success was defined as constructing a claim that could be defended with evidence. This was seen in her emphasis on the importance of having evidence to defend claims as seen in questions such as: "and what is your evidence of that?" Combining Ms. W's emphasis on aligning claims with evidence and her students revising their understandings in light of new evidence suggests that this classroom community has shifted the expectations such that the goal of the discussion is to construct claims that align with the evidence. Given this goal, revision becomes necessary as soon as new evidence is introduced to the discussion.

It is difficult to determine whether the students' apparent challenges with revising their understandings stemmed from the disconnect between goals of the activity or the difficulty, identified by D. Kuhn, of interpreting evidence in a way that results in revisions (1989; 1988; 2000). While future work could focus on this particular question, this data points to the conclusion that the challenges these students experienced grew more from the classroom context than an inability to align claims and evidence. First, across all four classrooms, students fluidly aligned claims and evidence as part of their involvement in classroom argumentation. Second, the coherence of the argumentative practice seen in each class provides additional evidence that the relatively low frequency with which students revised their ideas is connected to their interpretations of the practice. For example, the first three classes demonstrate ways that the goals of the activity can affect students' ability—or motivation—to connect their own ideas to those of their classmates such that they can learn from one another. In addition, in the one class that overcame this challenge, Ms. W, the teacher worked to create the expectation that students should revise their understandings in light of the evidence both in the immediate activity and throughout the year (as will be discussed in more length in Chapter 5).

This analysis indicates that the lack of revision seen in the first three classes is the result of students' interpretations of the task—the social context—rather than an inability. Thus, the challenge to educators becomes designing situations that motivate students to build on one another's ideas. In the language of the design strategies presented in Chapter 3, one might say that educators must "create a need for students to learn from one another."

4.7 SUMMARY

Figure 4.19 summarizes the four ways in which the classes in this study took up each of the aspects of scientific argumentation.

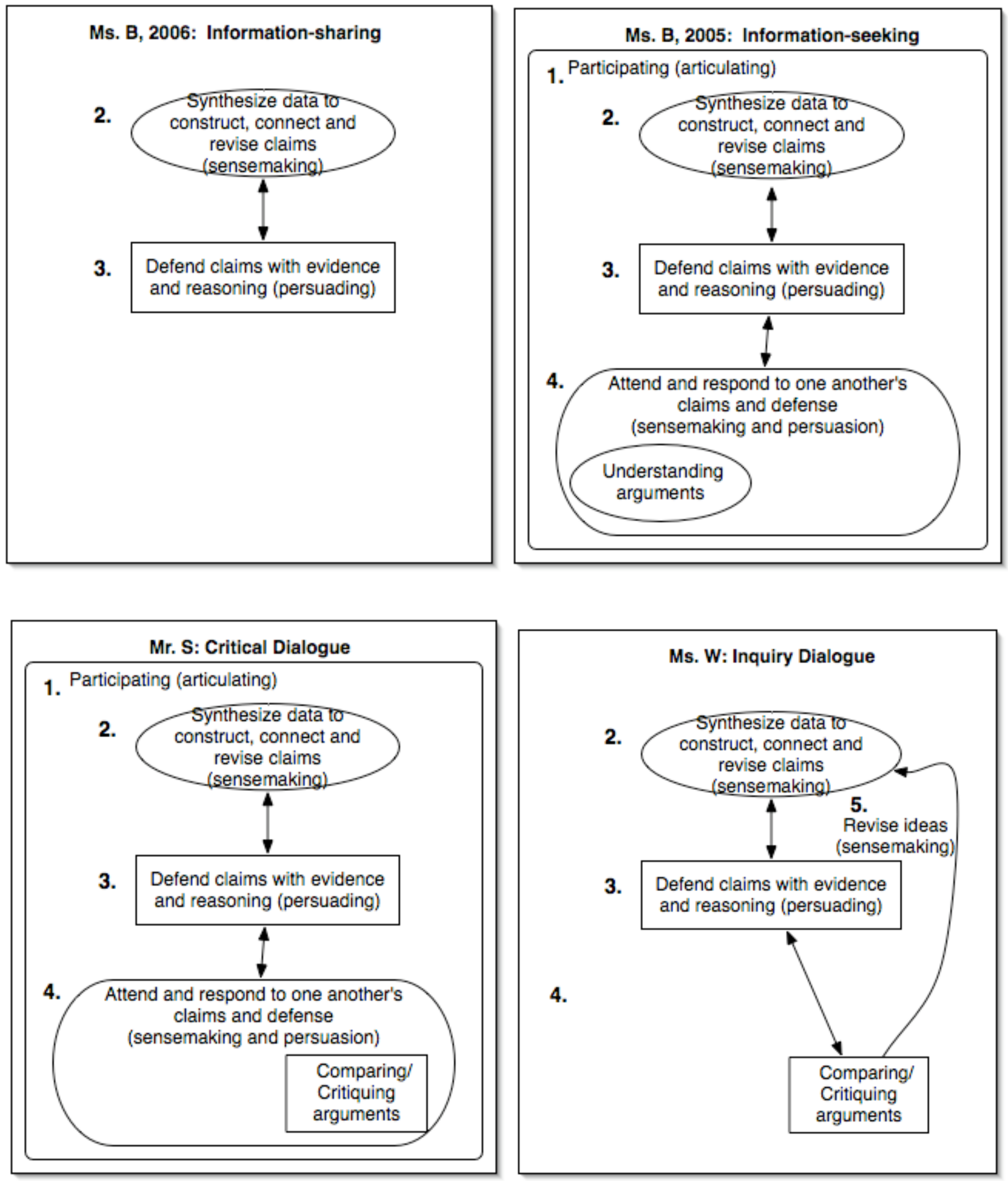

Figure 4.19: Four patterns of argumentation

As seen in Figure 4.19, I characterized students in Ms. B's 2006 class as engaging in argumentation as an opportunity to share. These students constructed initial claims and defended those claims without taking up the other aspects of argumentation. Mr. S' class, on the other hand, constructed claims, defended claims and attended to one another's ideas by comparing their arguments. This class struggled with moving beyond their disagreements to revise their ideas in light of one another's evidence. I characterized this class as aligning with Walton's persuasive or critical dialogue. Ms. B's 2005 class had a similar pattern in that her students constructed their arguments, defended their claims and attended to one another. However, rather than comparing arguments these students seemed to focus on understanding each individual argument as a stand-alone entity. In other words, these students engaged in an "information-seeking" form of argumentation in that they tried to understand one another's perspectives. Finally, Ms. W's students argued as a form of inquiry dialogue. They did this by focusing on the alignment between claims and evidence—construct claims that explicitly aligned with data, using that data to defend their claims, comparing one another's claims to the available evidence and revising their ideas accordingly.

Looking across these characterizations reveals that each of these adaptations of argumentation is internally consistent—they each achieve an activity goal. Thus, the challenges that emerge in each of these classes relates to the implicit goals of the activity. This suggests that, as discussed in Chapter 3, one might influence the ways in which students engage in this practice by manipulated the goals of the activity.

Chapter 5 extends this supposition by focusing on why each of these adaptations emerged in each class. That is, in this chapter I examined how each class' argumentative discourse was internally consistent. In the following chapter I explore why each class adapted the practice of scientific argumentation in the ways that they did.

CHAPTER 5: EXPLAINING THE ARGUMENTATIVE DISCOURSE THAT EMERGED IN EACH CLASS

In Chapter 1, I defined argumentation as discourse in which individuals work to make sense of phenomena, articulate understandings and persuade others of those understandings by: stating claims; defending claims with empirical evidence and accepted scientific theories; attending and responding to one another's ideas; and revising their own and other's arguments. I show Figure 5.1 here to review this definition of argumentation and the aspects of argumentative discourse.

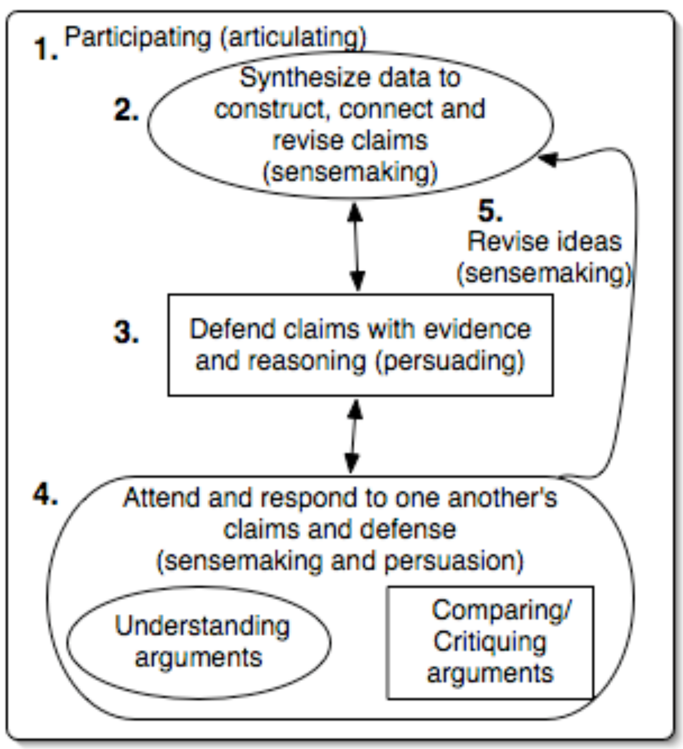

Figure 5.1: Review of the characteristics of argumentative discourse

As discussed in more length in Chapters 1 and 3, each of these discourse aspects may differ from the ways in which students typically interact with one another, their teacher and the content under study. Moreover, if the discourse aspects of typical classroom discussions differ greatly from those of scientific argumentation than this new practice will not make sense in the context of the classroom. As discussed by researchers who examine the relationship between practices, learning and participation (e.g. Cobb et al., 2001; Engestrom, 1999; Lave & Wenger, 1991), classroom communities resolve the tension between their typical ways of interacting and the expectations of a new practice—such as argumentation—by adapting the practice so that it makes sense in the context of the classroom. These adaptations are a composite practice such that the new practice reflects a combination of the interaction patterns of typical classroom practices and scientific argumentation. This composite practice enables students to engage in the argumentative practice without drastically transforming the ways in which they typically interact in the classroom.

In Chapter 4, I identified four different ways that the classroom communities with which I worked adopted and adapted the practice of scientific argumentation. I used Walton's dialogue types (1998) to name each of these forms of argumentation. This analysis revealed that:

1. Ms. B's 2006 class argued as a form of *idea sharing* in which the students stated and defended their claims while neither attending to the ideas of their classmates nor revising the ideas being discussed;

2. Mr. S' class engaged in a *critical dialogue* during the argumentative discussion in which the students responded to one another's proffered claims and justifications by evaluating and contradicting them in a competitive manner;

3. Ms. B's 2005 class' argument took the form of an *information-seeking dialogue* in that the students responded to one another's claims and justifications by asking questions, ostensibly to better understand each argument; and

4. Ms. W's class engaged in an *inquiry dialogue* in which the students were working with the teacher to revise their understandings by synthesizing the available evidence and competing understandings of the phenomenon under study.

In this chapter, I explore how and why these different adaptations of the practice came about. This exploration is designed to address my second research question: Why do classroom communities adapt scientific argumentation in the ways that they do? Investigating this requires examining how both the immediate learning environment (including teacher moves, curricular materials and activity structures) and the typical ways of interacting relate to the students' argumentative discourse. It is necessary to understand the first—the immediate learning environment—because, without it, I would be over attributing the impact of the typical classroom interaction patterns. That is, these students were not arguing in a vacuum: They were responding to prompts and scaffolds. Moreover, exploring the relationship between the immediate learning environment and students' adaptations of the practice informs future design work aimed at further fostering student argumentation.

In the following section I describe the analytical approach I used to explore how the adaptations of scientific argumentation in each class came about.

5.1 Analytical Approach

The analyses of student contributions during argumentative discussions (presented in Chapter 4) were driven by a need to identify differences and similarities across each class' argumentative discourse. Therefore, these analyses consisted of careful examinations of each variable illuminated by the coding scheme to discover those that had the most interesting patterns. In contrast, these analyses of why students engaged in these discussions in the ways that they did presented in this chapter began with these differences and similarities identified. Therefore I was able to focus on identifying aspects of the learning environments that could explain these particular patterns. To that end, this analysis was an iterative process of carefully describing the learning environment—including the supports that were immediately available and the typical interaction patterns—of each class individually, and then comparing across classes. As I made these comparisons, I identified characteristics of the learning environment that were described in one class and not another. I then returned to the data to fill in those gaps, thereby ensuring that the descriptions of each class included similar details. I connected these descriptions with relevant literature in order to identify those aspects of the learning environments that seemed most relevant to the ways in which the students in each class adapted and adopted the argumentative practice.

5.1.1 Relating student argumentative discourse to the immediate learning environments

The first step to understanding why students in each class argued in the ways that they did was to differentiate between those discourse characteristics that could be accounted for by the curricular materials and those that are better explained by class differences. The second step was to differentiate between class differences that emerged out of the immediate learning environment (e.g., the teacher's strategies and differences in the curriculum enactments) and those that were related to the class' respective existing classroom practices.

I explored the influence of the curricular materials by determining whether classes were affected by the argumentative activity in similar ways. For example, as will be shown in Figure 5.4, students in three of the classes made more justifying statements during the argumentative discussion than they did when argumentation was not a focus. Since this effect was seen in the majority of classes, I look to aspects of the argumentative lessons that were similar across those three learning environments and different from the fourth class, to explain it.

In contrast, when classes react to the argumentative activity in different ways, I assumed that variations between the classes must account for those differences. For example, as will be shown in Figure 5.5, students in two of the participating classes responded to one another directly much more during the argumentative lessons than they did during the typical discussions. However, students in the other two classes did not exhibit this sharp increase. Since this aspect of the students' argumentative discourse differed from class to class, I assumed that individual classroom characteristics (either differences in how the teacher structured the immediate activity or differences in the typical classroom interactions) would account for the differential effect of argumentative activity. I therefore looked for differences in the teacher moves that relevant literature indicated might explain these and other differences.

5.1.2 Relating student argumentative discourse to the typical ways of interacting

Moving beyond the immediate learning environment, I expected the existing interaction patterns—the ways students typically interacted with one another, the teacher and the content—to influence the ways in which students took up the scaffolds provided by the curricular materials and their teacher. In other words, I expected the existing ways of interacting to influence the ways students argued and to help explain the differential effects of argumentative activities. I explored this expectation by comparing the discourse that occurred in typical class discussions—those discussions that were not designed to foster scientific argumentation—to the argumentative discussions that occurred in each class.

Chapter 2 describes the procedure I used to identify the "typical" class discusses analyzed for this study. These entailed two three-minute intervals of every lesson in which argumentation was not a focus. Table 2.1 shows the number of typical lessons observed and the total number of minutes analyzed for each class.

I use the coding scheme described in Chapter 2 to elucidate differences in the kinds of things students say, whether and how students interact with one another, and how conflicting understandings were handled, in both the argumentative and typical discourse. The patterns that emerge from this coding allow me to characterize each class' discourse in terms of whether and how they engaged in each of the aspects of argumentation. I therefore use these codes to look for relationships between the aspects of argumentative discourse that are apparent in the students' argumentative and typical discussions. In particular, in order to examine the potential relationship between the ways in which students argued in the typical class discussions, I compared the frequency with which each class engaged in a particular aspect of argumentation during typical and argumentative discourse. For example, Section 5.3.2 will show that Mr. S' students emphasized evaluation over questioning during both typical and argumentative discussions. Thus, it appears that the emphasis on evaluation seen in the argumentative discussion in Mr. S' class may reflect an emphasis in the class' typical discussions rather than the supports found in the immediate learning environment.

The following analyses use this coding scheme and the characterizations of the immediate learning environments in order to understand address Research Question 2: Why do classroom communities adapt scientific argumentation in the ways that they do? Using the aspects of the argumentative discourse that stood out in the Chapter 4 analyses, I have unpacked this research question into three sub-questions:

2a. Students in all four classes consistently defended their claims. Why did students experience such consistent success with this aspect of argumentation?

2b. In two of the classes (Mr. S and Ms. B, 2005) students explicitly attended to one another's ideas. This was an exciting break from typical classroom interactions (Lemke, 1990; Mehan, 1979; Weiss et al., 2003). However, students in each of these classes did so in very different ways—Mr. S' students compared their understandings while Ms. B's students treated them as stand-alone entities to be understood. Why was this aspect of argumentative discourse differentially apparent in each class and why did they engage in it in such different ways?

2c. Why did only one class of students revise their understandings in light of the competing understandings?

In the following sections, I address each of these questions. For each question I explore how both the immediate learning environment and the existing discussion interaction patterns in each class could account for how and why each class engaged in the discourse characteristic under study in the ways that they did.

5.2 EXPLAINING HOW AND WHY STUDENTS DEFEND THEIR IDEAS

Recall that, across the four classes, students defended between 55 and 65% of the ideas they discussed during the argumentative lessons. This is the only aspect of argumentative discourse seen in the argumentative discourse of each class. In this section, I explore both the typical classroom discourse and the immediate learning environment in each class in order to understand why this aspect of argumentative discourse was so consistently apparent in the students' arguments.

In Chapter 4, I examined whether students justified their ideas by focusing on the "justification patterns." This step in the coding process examines multiple utterances, across student contributors, in order to identify instances in which ideas are added to the conversation and to determine whether those ideas have been justified. In this analysis, an "idea" is most frequently expressed as a claim, but it can also be an evaluation or a question.

Transcript 5.1 provides an example of an instance in which a student's question contributes a new idea that is justified during the discussion. This excerpt occurred as the Ms. B's 2005 class was discussing the difference between heritable traits (e.g., hair color) and non-heritable traits (e.g., muscle tone).

1	Teacher	If you go to the gym everyday and work out and get really big muscles and take steroids, are your children going to inherit your big muscles?	Questioning	
2	Students	No	Claim	
3	Sarah	But isn't like, if you take steroids, something could happen to the kid?	Questioning	Justified idea (Line 4 justifies the idea in Line 3
4	Unknown Student	Steroids could get into the genes.	Justifying	

Transcript 5.1: Example of a discussion in which a question becomes a justified idea. Taken from Observation 23 of Ms. B's 2005 class.

In Transcript 5.1, Sarah's question offers a contradictory claim to the discussion: The class seems to have agreed that children cannot inherit their parents' muscle tone and Sarah contradicts this by proposing that steroids could affect the unborn children. An unknown student adds to the conversation by justifying Sarah's idea: Maybe steroids effect the parent's genes. Although its scientific accuracy is questionable, this idea serves to validate Sarah's question and is therefore identified as a justification. Transcript 5.1 provides an example of a "justified idea" and, as such, illustrates how I combine multiple utterances to conduct the majority of the analyses discussed in this section.

I begin by examining whether and how the rate with which students justified their ideas during the argumentative discussions related to the classroom discourse during non-argumentative discussions and how the individual classes were differently affected. This analysis is designed to pinpoint the origin of the students' engagement with this aspect of argumentative discourse: If the lesson type (i.e., typical or argumentative) influenced each class in similar ways, than this would suggest that the rate with which students justified their ideas might be most directly affected by the lesson type. In contrast, large class differences would suggest that this discourse characteristic is tied to either individual teacher differences or differences in how the students and teachers typically interacted in each class.

Indeed, students justified their ideas at different rates during argumentative and typical class discussions: Looking across the classes, students justified 62% of their ideas during the argumentative discussions and only 38% during the typical class discussions. This comparison suggests that students justified relatively more of the ideas they discussed during argumentative discussions than they did during typical discussions. In order to understand the source of this increase, I separate the classes: do all classes exhibit a similar increase?

Figure 5.2 shows the average number of justified ideas discussed by students during each three-minute interval during the typical and argumentative discussions of each class.

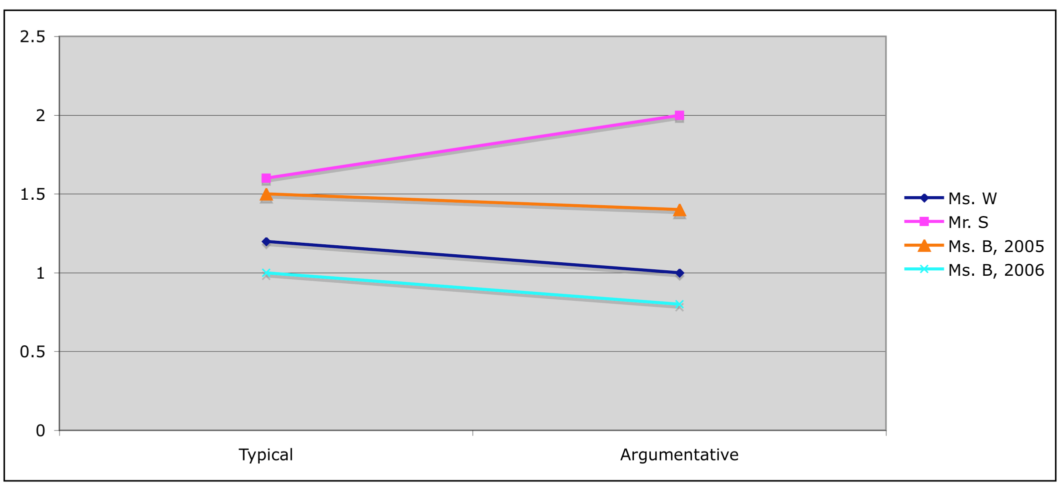

Figure 5.2: Average number of justified ideas discussed by students in each three-minute interval during the typical and argumentative discussions in each class.

Despite the presence of a greater proportion of justified ideas in the argumentative lessons, as seen in Figure 5.2, the lesson type does not seem to affect the average number of justified ideas discussed in each class. For example, Mr. S's class shows the greatest change and that class justifies only 0.4 more ideas per three-minute interval during argumentative discussions than they do during non-argumentative (or "typical") class discussions. If the number of justified ideas did not change, then the increased proportion of justified ideas suggests that the total number of ideas discussed in the argumentative discussions must be lower then the number discussed in the typical discussions.

In fact, as seen in Figure 5.3, the proportion of justified ideas changed because the students discussed fewer ideas (justified and unjustified) during the argumentative discussions then they did during the typical discussions. Thus, a greater proportion of their ideas were justified.

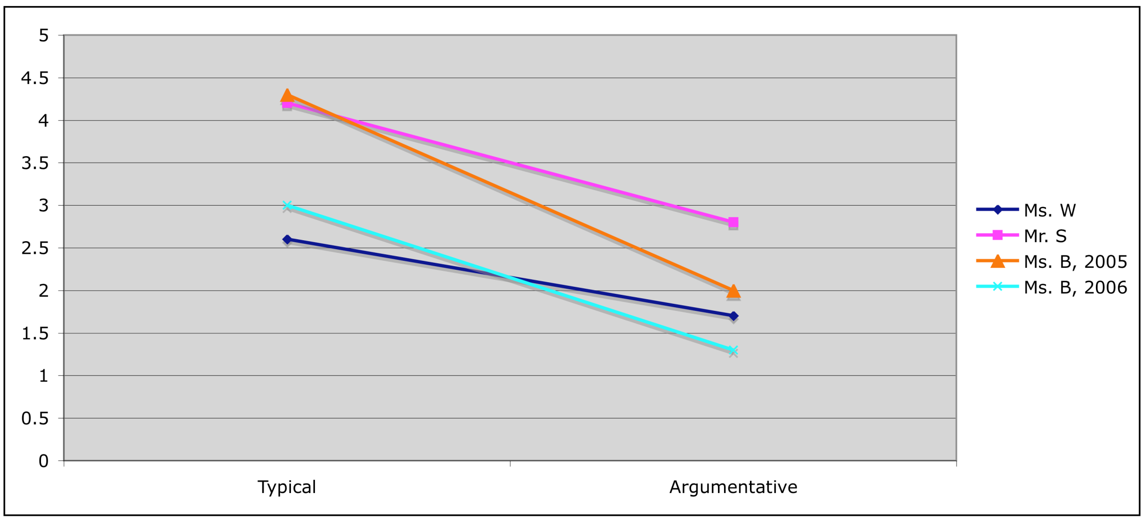

Figure 5.3: Average number of unique ideas discussed by students in each three-minute interval during the typical and argumentative discussions in each class.

As seen in Figure 5.3, regardless of the starting point (i.e., regardless of the number of ideas students in each class discussed during typical discourse), students in all classes appear to discuss fewer ideas during typical discussions than they did during argumentative.

One possible interpretation of this result is that the students discussed fewer ideas because each idea was discussed for more time and in greater depth. In fact, collapsing the classes reveals that students offered about one and a half justifications (1.49) for every idea discussed during their typical lessons while they offered just over two justifications (2.11) for every idea in their argumentative lessons. Thus, having more justifications during a three-minute interval of argumentative discourse than they do during typical discussions, while decreasing in the number of ideas stated, suggests that each unique idea was getting more justifications; students were discussing each idea in more depth.

Transcript 5.2, taken from a typical discussion in Ms. B's 2005 class, illustrates a discussion in which an idea is justified with a single statement. In this discussion, the class was identifying possible factors that could have caused the Finch population on the Galapagos Islands to decrease suddenly (Reiser et al., 2001; Tabak et al., 1996).

1	Student	If this an island, they probably didn't have a drought	Evaluating	Justified idea (Line 2 justifies Line 1)
2	Student	'cause islands are surrounded by water.	Justifying	
3	Teacher	Well, we'll find out more tomorrow and then we can revise this list. We can add some more stuff to that.	Non-argumentative	

Transcript 5.2: Example of an idea being justified with a single statement, taken from Observation 17 in Ms. B's 2005 class

Transcript 5.2 shows a student introducing a new idea by stating an evaluative comment (i.e., a drought did not kill the birds) and justifying that idea with a single piece of information (i.e., a drought doesn't make sense if the islands are surrounded by water). The teacher responded to the student's justified idea by attempting to conclude the conversation—stating that the students would be able to explore all the possible causes the following day. Thus, this idea is justified by only one statement (Line 2). In contrast, recall Transcript 4.10 in which a student's question inspired the presenting group to contribute three additional statements that justified their claim that the invader ate grass.

Figure 5.4 shows that the contrast seen between Transcript 5.2 and 4.10 holds true: In general, students tended to contribute more justifications during argumentative lessons (such as Transcript 4.10) than they did during typical (such as Transcript 5.2).

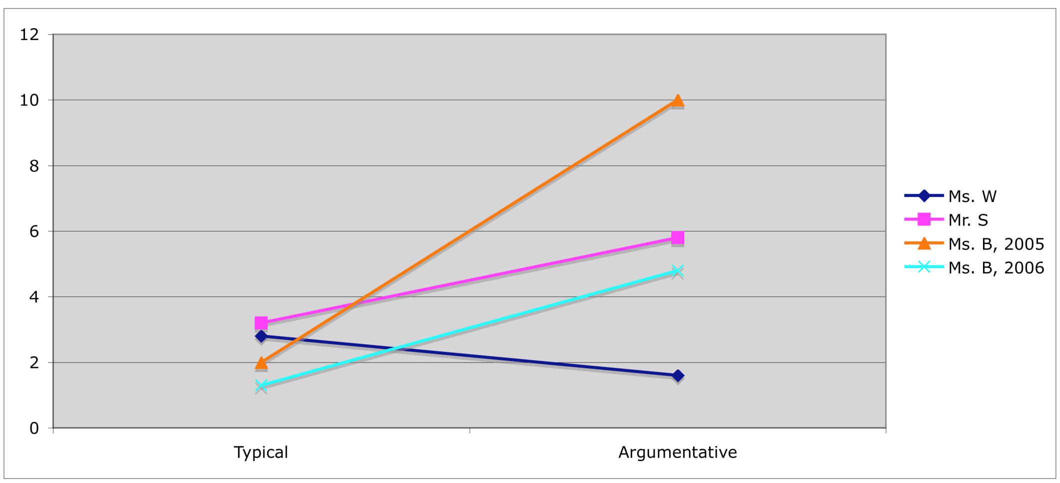

Figure 5.4: Average number of justifying utterances contributed by students in each three-minute interval during the typical and argumentative discussions in each class.

As seen in Figure 5.4, not all classes reacted to the argumentative discussions in the same ways. It appears that Ms. W's students do not show the same increase that is evident in the discourse of the other three classes.

I began this analysis of the justification patterns with the finding from Chapter 4: Students in all classes justified more than half of their ideas during the argumentative discussions. This finding indicated that defending ideas was an aspect of argumentative discourse in which students in all classes could engage, regardless of differences across the classes. In this section, I unpacked this finding to understand the ways that the lesson type differently affected the four participating classes. Three findings emerge from these analyses:

1. As seen in Figure 5.2, students in all classes justified approximately the same number of ideas during argumentative discussions as they did during typical. However, students discussed fewer ideas during each three-minute interval than they did during their typical class discussions (Figure 5.3). This suggests that students were more likely to defend their ideas during argumentative discourse than they were during non-argumentative, or typical, discussions.

2. Students that participated in the Whole Class Debate (Ms. B's two classes and Mr. S' single class) made more justifying contributions during the argumentative discussions than they did during the typical (Figure 5.4). Therefore, the reduction in ideas seen in these classes indicates that students discussed their ideas at more depth during the Invasive Species Whole Class Debate than they did during typical class discussions.

3. Ms. W's class differed from the others: these students discussed fewer ideas than did students in the other classes and contributed as many justifying statements during typical discourse as they did during argumentative. This suggests that the argumentative lessons did not have a large effect on whether and how students in Ms. W's class defended their ideas—they did so similarly across both their argumentative and non-argumentative lesson types.

Combining these findings indicates that, while students in all four classes provided evidence that they defended of their ideas during the argumentative discourse, the lesson type affected the classes differently: The argumentative discourse appears to have increased the depth with which students discussed their ideas in three of the classes and not affected the justification patterns in the fourth participating class (Ms. W).

These findings inform the following discussion regarding why students in all four classes justified more than half of their ideas during their argumentative discourse and why, even with this consistency, the classes were differentially affected by the lesson type. I do this by exploring how the immediate learning environment and existing ways of interacting can each help explain these findings.

5.2.1 How did the immediate learning environment influence students defending their ideas?

As will be discussed throughout this chapter, the argumentative discussions were supported differently in each class. For example, Mr. S set up the activity and then sat in the back of the room without guiding student participation while, in 2005, Ms. B provided her students with a set of questions and criteria for how to evaluate one another's arguments. In contrast, the immediate learning environment of Ms. W's class greatly differed from that of the other three classes: Ms. W's students did not engage in the Whole Class Debate that was analyzed for the other three classes. Instead Ms. W's class engaged in teacher-led argumentative discussions.

As shown in the previous section, students in all four classes justified more than half of their ideas during their argumentative discussions. Moreover, the three classes that enacted the Invasive Species Whole Class Debate all decreased the number of ideas (shown in Figure 5.3) they discussed because they tended to spend more class time discussing—and justifying—each idea (shown in Figure 5.4). Ms. W's students, on the other hand, did not exhibit this change: Students in this class justified their ideas at about the same relative rate and with the same number of justifying utterances across both contexts. I use this contrast to organize my analysis of the relationship between the immediate learning environment and the students defending their ideas: How was the learning environment of the Invasive Species Whole Class Debate similar across the three classes that enacted it and different from Ms. W's class? Can this comparison explain the justification patterns found in these classes?

The most striking commonality across the four participating classes is that they were enacting a unit designed to foster argumentative discourse by using three design strategies (described in detail in Chapter 3). These strategies were:

1. *Making the epistemic criteria* explicit by providing students with an instructional framework to guide their construction of written arguments;

2. *Creating a need for students to use evidence* by constructing problem scenarios that had multiple plausible answers such that students had to use evidence in order to choose between these different possibilities; and

3. *Creating a need for students to argue* through activities that have a goal that can only be accomplished when students attend to the ideas of their classmates.

The Invasive Species Whole class Debate was designed in accordance with each of these strategies while the argumentative discussions in Ms. W's class followed only strategies 1 and 2. In this section, I use relevant research and cross class-comparisons to connect the enactment of these strategies to the students' defense of their ideas.

Strategy 1, Making epistemic criteria explicit: First, as discussed in Chapter 3, the IQWST instructional framework for argumentation was designed to make the epistemic criteria for argumentation explicit by elucidating key components of an argument, including:

- *Claim*: the answer to the question
- *Evidence*: information or data that supports the claim
- *Reasoning*: a justification that shows why the data count as evidence to support the claim

Teachers of all four classes presented their students with this framework early in the unit and periodically asked them to use the framework to write "scientific explanations" (the term used in the IQWST unit for written arguments).

McNeill et al. (2006) found that this framework supports students in justifying their claims when writing scientific explanations (or arguments). That students justified over half of their ideas during all argumentative discussions analyzed is therefore consistent with McNeill's findings, and may indicate that this framework supports students in defending their ideas when constructing verbal arguments as well as written. However, students in all of these classes discussed and used this framework in lessons that did not focus on argumentation—in 'typical' discussions. Thus, the use of the instructional framework does not explain why the enactments of the Invasive Species Whole Class Debate reveal students offering more justifying utterances for each idea than they did during typical class discussions. That is, while it is possible—and given McNeill's work, even likely—that the IQWST framework is one reason that students in all four classes justified their ideas during the argumentative lessons, the instructional framework does not explain the changes seen in the three classes that enacted the Whole Class Debate.

Strategy 2, Creating a need for students to use evidence: Strategy two may partially account for both the relative frequency with which students justified their ideas and the relatively high number of justifications used to do so during Whole Class Debate. Each of the lessons designed to foster argumentation created a need for students to use evidence by designing problem contexts in which students were exploring complex data sets that could support multiple answers. For example, the students discussing the invasive species were asked what it ate and generating (via manipulations of the simulated ecosystem) data that could reasonably support multiple claims. Similarly, students in Ms. W's class were asked two questions about which they disagreed from the outset: 1) whether the microscopic things they observed were living and 2) whether plants need soil to survive. In each of these situations, students were either given or collected data they could use to choose between the competing answers to the question being investigated.

I suggest that the discussion of contentious questions facilitated the students in justifying their ideas. As seen by Bricker and Bell (2007), students consistently justify their claims when engaged in everyday arguments. Thus, this is a skill that students have and the challenge is to create situations that motivate them to do so in science classrooms. As discussed in Chapter 3, asking students questions that have multiple plausible answers does this—it creates a need for students to justify their ideas in order to choose between them (de Vries et al., 2002; Hatano & Inagaki, 1991). That is, the mere fact that there was disagreement may have created a situation that motivated students to defend their claims. Moreover that students in all four participating classes justified more than half of their ideas during the argumentative lessons provides evidence that this design strategy may have created a need for students to justify their ideas[23].

However, there were differences across these classrooms. Most strikingly, students in three of the classes offered more justifications during the argumentative discussions than they did during their typical discussions while Ms. W's students do not exhibit a similar increase. In other words, while this strategy was enacted across classrooms, the same justification patterns did not emerge in all of the participating classrooms. One possible explanation for this difference lies in the details of how this strategy was enacted: the students that partook in the Invasive Species Whole Class Debate were manipulating data and discussing interpretations of data they collected while Ms. W's students were discussing interpretations of data that was either supplied

[23] This analysis does not explore whether these justifications used evidence. Future analyses could do so. In this discussion, it seems sufficient to say that rich problem contexts were frequently paired with relatively high rates of student justifications.

by the curricular materials or collected in a single observation that did not afford further investigation.

Future analyses could explore these different variations on this strategy in order to more fully unpack the factors that influence how and when students justify their ideas. For this current analysis, I conclude that, while design strategy 2 may have facilitated students in defending their ideas, it does not have a consistent effect.

Strategy 3, Creating a need for students to argue: The Whole Class Debate activity structure was paired with the Argument Jigsaw (described in Chapter 3 but not analyzed in this dissertation) to create a need for students to argue: These activity structures are designed to give students a goal that can only be achieved when students attend and respond to one another's ideas. That is, in both of these activity structures students were tasked with comparing across their explanations of the phenomenon under study in order to reach consensus, and it was hoped that this consensus could only be reached if students attended and responded to one another's ideas in a substantive way. The Invasive Species Whole Class Debate—enacted by Ms. B's 2005 and 2006 classes and Mr. S' class—follows this design strategy. The fourth class, Ms. W's class, differed from the other three in that they were not enacting an activity that was designed to create a need for students to argue; the teacher-led argumentative discussions did not have an explicit goal designed to motivate students to attend to one another's ideas.

It is possible that the goal of consensus building facilitated the increased depth with which students justified their ideas during the Invasive Species Debate. Each of the enactments of this activity utilized a combination of formal presentations and students challenging one another and the formal presentations were key opportunities for students to offer multiple justifications for their claims. The formal presentations were instances in which students were tasked with describing everything they knew about the phenomenon under study. Thus, it may be that the increased depth of student justifications seen—the tendency of students enacting the Invasive Species Whole Class Debate to offer more justifications per three-minute interval during the debate than they did during typical class discussions—may be largely due to the activity structure in which students were given an opportunity to express multiple supports for each of their ideas.

This analysis reveals that it is possible to attribute the high rate with which students in all four classes justified their ideas during the argumentative discussions to the design strategies employed by the IQWST team. However, without further investigations into the specifics of the implementation of these design strategies, it is not possible to fully understand their impact student discourse. Possible questions include:

1. How does the students' personal access to the data collection and interpretation (via NetLogo in this case) relate to the frequency with which they justify their ideas and the number of justifications they use to do so?

2. Is it possible to "create a need for students to argue" without employing a formal presentation activity? If so, how would the informal student-led argumentative discussions impact the frequency with which students justified their ideas and the number of justifications they use to do so?

These questions introduce possible future studies. In the current study, I focus on the finding that all three classes that enacted the Invasive Species Whole Class Debate increased in the number of justifications they discussed, regardless of cross-class differences. The fourth class, Ms. W's class, did not enact a Whole Class Debate and did not exhibit a similar increase when the students' typical discourse was compared to their argumentative. This indicates that the Whole Class Debate may have facilitated the increased number of justifications seen. Broadly, this suggests that this aspect of argumentative discourse—the defense of ideas—may by be something that can be influenced via curriculum design.

The following section explores whether and how the typical interaction patterns influenced student defense of their ideas. The theory driving this work is that the existing ways of interacting will affect how students engage in each of the aspects of scientific argumentation. If this were true, why would the complex problems (strategy 2) and Whole Class Debate (strategy 3) affect the classes in similar ways?

5.2.2 How did the existing ways of interacting affect student defense of ideas?

The above analysis highlights ways that the activity structures and curricular materials may account for why students in all four classes justified more than 50% of their ideas during their argumentative discussions, and why the three classes that enacted the Whole Class Debate offered more justifying statements during the debate than they did during typical class discussions. This similarity raises the question of whether the existing classroom practices influenced the students' defend of their ideas. I explore that question in this section. I hypothesize that this consistency is the result of typical classroom discourse in all classes. Figure 5.2 illustrates that students in all four classes justified about the same number of ideas during typical class discussions as they did during argumentative discussions. That is, students in all four classes were already participating in this aspect of argumentative discourse.

Moreover, the defense of ideas is an aspect of argumentative discourse that can occur without transforming student-teacher interactions. For example, in Ms. W's argumentative discussions the students justified their ideas when prompted to do so during participating in a teacher-led discussion. Transcript 5.3 provides an example of an instance in which a teacher, in this case, Ms. B in 2005, prompts her student to justify a claim on which the class has agreed. This interaction reveals a student justifying his claim during the most common student-teacher interaction: IRE (Lemke, 1990; Mehan, 1979).

1	Teacher	So, how do we know? We seem to be in agreement	Questioning
2	Mikaili	[When everything is alive]	Justifying
3	Teacher	How do we know that one of these is not stable and the other 2 are stable? How do we know that? Toby?	Non-argumentative
4	Toby	When the lines, when they meet 0 or the bottom of the graph then that is when we know that it is unstable	Justifying
5	Toby	because nothing survived. I mean, if one of them didn't survive then it isn't stable. But…	Justifying
6	Teacher	Okay.	Evaluating

Transcript 5.3: Example of a student justifying his claim during an IRE exchange (taken from observation 12 of Ms. B's 2005 class)

In Transcript 5.3, Ms. B's 2005 class has been examining population graphs in order to determine whether the populations are stable even though the populations are changing size (the graph shown in Chapter 3 is an example of this). After the class agreed on whether each graph represented a stable population, the teacher asked the students to justify their claims, saying: "How do we know?" Toby complied with this request by identifying the characteristics of an unstable graph: he defended the claim that one of the graphs is not stable by defining the term being discussed. In Line 6, Ms. B evaluated Toby's justification. Through this, Toby and Ms. W were engaged a prototypical initiate-respond-evaluate exchange; Ms. B *initiated* the exchange by asking for a justification (Line 3), Toby *responded* by justifying the claim (Lines 4 and 5) and Ms. B *evaluated* his response (Line 6). As discussed in Chapters 1 and 3, as well as work by Lemke (1990) and Mehan (1979), this is the most common of classroom interactions.

Transcript 5.3 illustrates that students can be prompted to justify their claims in standard classroom interactions. Combined with Figure 5.2 that shows that the justification of ideas was an aspect of argumentative discourse with which the students were already familiar, this suggests that the defense of ideas is an aspect of argumentative discourse in which students can engage without substantially transforming the ways in which they typically interact in a classroom. Thus, it may be that the justification of ideas is "low hanging fruit" for students as they engaged in scientific arguments; it may be that this was an aspect of argumentative discourse with which students were already familiar and could therefore readily do during their argumentative discussions. This result is consistent with the work of Bricker and Bell (2007) in which they found that children are likely to justify their ideas in many contexts, and suggests that, rather than teaching students to justify their ideas, educators simply have to create contexts in which the students have a reason to do so. Moreover, as seen in Transcript 5.3, it may not be difficult to create these contexts: it may be that simply asking students to justify their ideas accomplishes this goal. That said, it appears that creating contexts in which justification of ideas makes sense—contexts in which justifications accomplish something other than responding to a teacher prompt—may result in more in-depth justifications. This is seen in the increased number of justifications offered by students as they engaged in the Invasive Species Whole Class Debate, when compared to their typical class discussions.

In summary, it appears that students in all four classes exhibited this aspect of argumentative discourse—they defended more than 50% of the ideas they discussed—because both the typical classroom discourse and the immediate learning environments supported it. The existing classroom discussions reveal that this aspect of argumentation is something with which the students are familiar and may require little explicit instruction to do. In addition, it appears that classroom interaction patterns do not have to transform in order to prompt students to defend their ideas. Thus, it was possible for students in Ms. W's class to justify their ideas at a high rate during the argumentative discussions while participating in a teacher-led discussion. Analysis of the immediate learning environment indicates that the students' facility with this aspect of argumentation can be built upon by creating environments in which students have a reason to offer multiple justifications for each idea discussed—to add depth to their discussions

5.3 EXPLAINING HOW AND WHY STUDENTS ATTENDED TO ONE ANOTHER'S IDEAS

The second important difference that emerged out of the analysis presented in Chapter 4 was that students in each of the participating classes attended to one another's ideas differently—as seen in the frequency with which they responded to one another's ideas and in the content of those interactions. Two classes—Ms. B 2005 and Mr. S—exhibited high rates of student-to-student interactions (more than 70% of the interactions in these classes involved students responding to one another), while students in the two other classes—Ms. B 2006 and Ms. W—responded to one another at much lower rates (less than 40% of the interactions in these classes were student-to-student). Moreover, in the two classes in which students frequently responded to one another's ideas, they did so in different ways. Mr. S' students engaged in argumentation as a form of critical dialogue in which they frequently evaluated and contradicted one another's ideas. In contrast, Ms. B's 2005 students engaged in an information-seeking dialogue in which they questioned one another but rarely explicitly discussed points of agreement and disagreement. In this section, I explore how the immediate learning environments and typical ways of interacting for each class can explain the unique ways that students in each class engaged with one another's ideas. That is, in this section I explore the following questions:

1. How do the curricular materials help explain the rate with which students responded to one another in all classes?

2. How does the immediate learning environment and existing classroom norms help explain the differential rates of student-to-student interactions found in the four classes?

3. In those classes in which students frequently responded to one another (Ms. B, 2005 and Mr. S) how does the immediate learning environment and typical interaction patterns help explain the content of the student-to-student interactions (e.g., the students' different emphases on questioning and evaluating one another)?

5.3.1 How do the curricular materials explain the rate with which students responded to one another?

As I did in my analysis of why students in all four classes successfully defended their ideas, I begin by attempting to tease apart the effect of individual class differences and those of the curricular materials. That is, while there are clearly cross class differences in how much students responded to one another (and the content of those interactions), a consistent effect of the argumentative activity (e.g., if students in all four classes respond to one another more during the argumentative discussion than they do during typical) would indicate this aspect of the students' discourse was influenced by both individual class differences and the curricular materials. I explore this possibility in this section.

I investigate how and why students attended to one another's ideas by comparing the frequency with which they responded to one another across classes and lesson types. Figure 5.5 presents this comparison.

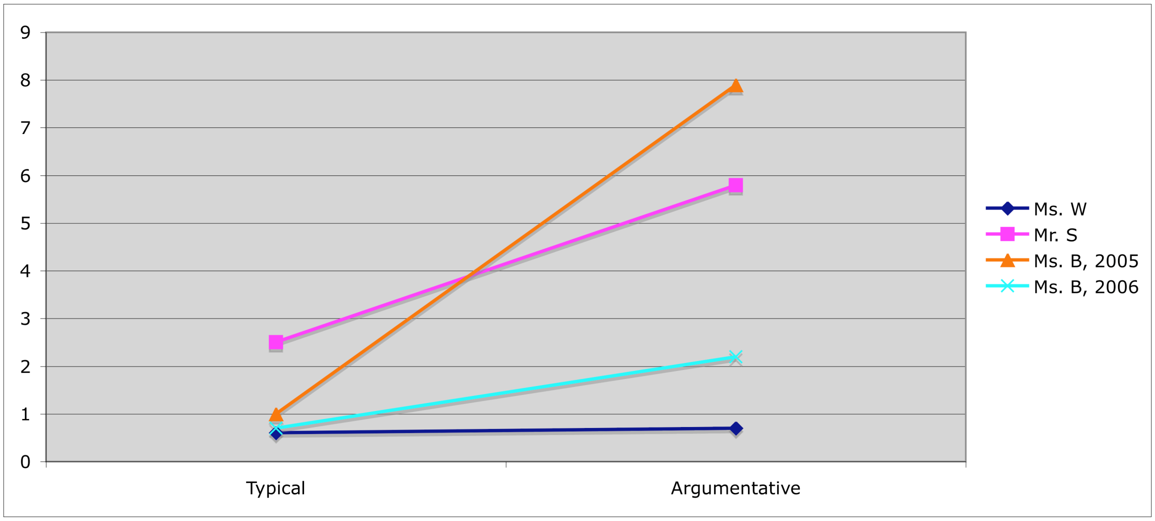

Figure 5.5: Effect of argumentative lessons on the frequency with which students responded directly to one another, across classes

As seen in Figure 5.5, there was a much larger amount of student-to-student discourse during the argumentative lessons than the typical. However, this influence of lesson type appeared to differ across the four classes. That is, as Figure 5.5 suggests, students in both of Ms. B's two classes and Mr. S' class all responded to one another more during the argumentative lessons than they did during the typical, while Ms. W's students responded to one another at a consistent rate, across the two lesson types. In other words, as was seen in the analysis of students' justifying their ideas, students that enacted the Invasive Species Whole Class Debate show a consistent effect of lesson type (they all increased the rate with which they responded to one another's ideas when compared to their typical discussions) while Ms. W's students do not. As discussed in Section 5.2, the one design difference across the argumentative lessons enacted in Ms. W's class and the Invasive Species Whole Class Debate is that Ms. W's argumentative discussions were not designed to create a need for students to attend and respond to one another. The Invasive Species Whole Class Debate, on the other hand, was designed to give students an explicit goal that required them to do so: In this lesson, we asked students to reach consensus regarding the invasive species' food. That all enactments of this activity structure show students responding to one another more than they did during typical class discussions indicates that the Whole Class Debate was largely successful in fostering these interactions. In addition, given that typical classroom interactions inhibit students' ability and motivation to respond to one another (Hatano & Inagaki, 1991; Herrenkohl et al., 1999; Hogan & Corey, 2001; Lemke, 1990), it is not surprising that a similar increase is not seen in Ms. W's class during their argumentative discussions in which this challenge was not explicitly addressed through the activity design.

This discussion suggests that the Whole Class Debate activity can help explain why students responded to one another more often during the argumentative lessons than they did during the typical. However, it does not explain the individual class differences. In the following section, I explore how the individual learning environments in each class—both in terms of the immediate learning environment and typical ways of interacting—influenced whether and how students responded to one another's ideas. This analysis addresses the final two questions raised in this section.

5.3.2 How do the individual learning environments explain how and why students respond to one another's ideas?

In the previous section, I found that the students that participated in the Invasive Species Whole Class Debate responded to one another more often during these debates than they did during typical class discussions. In addition, I found that Ms. W's students did not increase—these students responded to one another at similar rates across both typical and argumentative lessons. Since this lack of an increase can largely be explained by the activity structure (i.e., Ms.

W's students did not enact an activity explicitly designed to foster student-to-student interactions), I do not include this class in the examination of individual class differences: it is neither necessary to understand their enactment nor a fair comparison. Instead, I focus only on those classes in which students enacted the Invasive Species Whole Class Debate—Ms. B's two classes and Mr. S' single class—in order to explain differences in how and why these students responded to one another.

Figure 5.5 underscores the differences discussed in Chapter 4: It appears that Ms. B's 2005 students responded to one another's ideas more frequently than do students in Mr. S' class who appear to do so more than Ms. B's 2006 students. Thus, in this section I explore how the individual learning environments found in each class—both the immediate learning environments and the existing classroom interaction patterns—explain the different relative rates with which students responded to one another. Why did the Whole Class Debate have a different impact on Ms. B's 2005 and Mr. S' respective classes differently than it did on Ms. B's 2006 class?

Beyond the frequency with which students responded directly to one another's ideas, Chapter 4 revealed that the content of these responses differed across classes. In particular, while Mr. S' students and Ms. B's 2005 students responded to their classmates' ideas at similar rates, they did so in different ways: Mr. S' students were more than twice as likely to evaluate as they were to question one another's ideas while Ms. B's 2005 students evaluated and questioned at equivalent rates. This comparison raises the final question addressed in this analysis: How can the individual learning environments explain differences in how the students responded to one another?

In order to explore how the individual learning environments influenced whether and how students responded to one another, I explore variations in each of the classes. For each class I relate the immediate learning environment—in terms of the teacher's practice as the analysis of the activity structure and curricular materials was completed in Section 5.2—and the existing interaction patterns to the student-to-student interactions.

5.3.2.1 Mr. S

As described in Chapter 4, Mr. S' students' argumentative discourse resembled Walton's (1998) persuasive-dialogue. These students frequently responded to one another's ideas, and they did so by evaluating and contradicting them. In the following sections, I provide details regarding Mr. S' teaching strategies and the typical classroom interactions in order to explore why students may have responded to one another's ideas in this way.

5.3.2.1.1 How did Mr. S facilitate student-to-student interactions

In Section 5.3.1, I demonstrated that the Whole Class Debate activity structure facilitated the student-to-student interactions. In this section, I refine that conclusion by exploring how aspects of Mr. S' teaching strategies can explain the unique ways in which students in this class engaged with one another's ideas. In particular, I focus on the findings that: 1) Mr. S' students responded to one another's ideas relatively frequently and 2) the substance of those contributions differed from Ms. B's 2005 class.

I explore ways that Mr. S facilitated student-to-student interactions by describing his role in the Whole Class Debate, overall. Before the Invasive Species Whole Class Debate began, Mr. S asked his students to form groups around common claims. Once the students finished re-grouping, he had three groups: one claimed the invader ate rabbits, another claimed it ate grass and the third argued that the invader ate all three native species (grass, rabbits and foxes). Mr. S then had his students face the back wall so they could see a projection of the Netlogo model (the back wall was his only projection space) (Wilensky, 1999).

Mr. S then attempted to get a run of the NetLogo model that students could use when presenting their arguments. He needed the model to show population fluctuations before and after the invader entered the simulated ecosystem. However, Mr. S had spent the days in which students explored the computer model managing the laptop checkout program and student behavior. He was therefore unfamiliar with the computer program and he struggled with creating a stable ecosystem for his students to use. As he attempted to get the model working, his students called out suggestions regarding model settings that would result in a stable ecosystem. Transcript 5.4 provides an excerpt from this approximately six-minute discussion and exemplifies the students' expertise and the teacher's inexperience with the software.

1	Teacher	It died didn't it? Let's try it again.
2	Joshua	Mr. S. can I go next?
3	Joshua	Mr. S., the offspring is too much. It's wise not to let it past 6.
4	Teacher	Okay. Thank you.
5	Student	It's not true
6	Students	[laugh at what happens on the graph]
7	Student	They eat the grass, they eat grass
8	Student	Aww it's too late, you supposed ta start, you click START when you press SET-UP… [inaudible because of students talking over each other.]
9	Student	Mr. S. they eat grass?
10	Student	No
11	Student	Rabbits
12	Joshua	Mr. S., I know what to do.
13	Emmanual	Increase the number of whachama-call-its!

Transcript 5.4: Excerpt from the beginning of class on the day of the Whole Class Debate

Transcript 5.4 shows students in this classroom acting like they had more expertise about the simulated ecosystem than their teacher. For example, in Line 3, Joshua offered his explanation as to why the model was not working. He even told his teacher that what the teacher had done so far was "not wise." Mr. S responded to this by thanking Joshua and implementing the suggestion. (Mr. S reduced the offspring variable and re-ran the model while an unidentified student contradicted Joshua's suggestion.) Lines 9 - 11 provide an additional example of the student authority over the content of the simulated ecosystem: In these lines a student directed a question to the teacher, but rather than waiting for Mr. S' response, two students interrupted and stated their own claims—their own answers to his question.

Interactions such as these suggest that Mr. S' students were accepted as authorities over how the model worked and how to interpret it. Not only did these students tell their teacher how to work the model, but he accepted and followed their advice. Furthermore, when a student asked a question that required an interpretation of the model's behavior (Line 9), students answered the question—rather than Mr. S.

Upon successfully getting the computer model to run, Mr. S sat down behind his students (in what was usually the front of the room), and gave them a yardstick that they could use to both identify particular points on the projected model and to control who was speaking (students had to have the yard stick to speak). He identified three students—one from each group—to represent their group's respective arguments. Mr. S' intent was that students would rotate through these three presentations and then allow the observing students to question the three presenters. He apparently expected to repeat this presentation and questioning cycle a few times during the Whole Class Debate.

However, as discussed in Chapter 4, students in Mr. S' room did not follow his expectation. The starkest example of students differing from the teacher's expectation occurred at the conclusion of the first presentation. Transcript 5.5 illustrates how this presentation broke from the teacher's expectation by showing the transition from a student presenting to students responding to the presentation.

1	Teacher	Okay. Okay. And you did give some evidence of that.
2	Student (in the audience)	Can I say something?
3	Teacher	Hold on, we'll come back.
4	Joshua	Can I take questions?
5	Teacher	Any questions for him?
6	Joshua	Any questions?

Transcript 5.5: Shows a student and teacher negotiation for control of discussion in Mr. S' class

In Line 1 of Transcript 5.5, Mr. S evaluated Joshua's presentation. An unidentified student then bid for a turn to speak and the teacher denied his request—it appears that, at this point in the discussion, Mr. S was still hoping to move through three presentations before allowing students to ask one another questions. However, Joshua responded to the teacher's denial by repeating the request for the students to take the floor by asking if he could take questions. In Line 5, the teacher acquiesced by asking if any student would like to ask Joshua questions. Joshua then took control from the teacher, repeating the teacher's invitation for questions. Following this prompt, Joshua took a question that resulted in about two minutes of discussion and debate.

Transcript 5.5 provides an example of the students and teacher negotiating the structure of the Whole Class Debate as it unfolded, both in terms of whether students could interrupt the presentations to ask questions and in terms of who (student or teacher) would manage the discussion. In this case, Mr. S ceded control to Joshua and allowed students to question his argument. More subtle forms of this negotiation occurred throughout the Whole Class Debate when students called out questions and challenges. Mr. S responded to these interruptions differently at different tines in the discussion: sometimes he allowed them without comment and at other points he rejected the student's interruption by identifying the next, legitimized, student speaker.

As will be shown in the discussion of Ms. B's 2005 Whole Class Debate, this negotiation over who was going to manage the discourse and when students were allowed to speak is not a requirement of the debate structure. Instead, it may have arisen in this class as a result of the lack of explicit structure provided to students, and the students' confidence in their expertise. That is, unlike Ms. B, Mr. S never explicitly established the behavioral expectations for the Whole Class Debate. He never said: "we will listen to three presentations and then ask those presenters questions." Without this communication, students were left to engage in the Whole Class Debate in the way that made the most sense to them, and, given Mr. S' lack of familiarity with the domain of the debate, it appears that the most sensible way to argue was for the students to interact directly with one another, rather than await the teacher's evaluation.

It is important to note that Mr. S' students were not always allowed to manage the discussion and accepted as content experts: Mr. S took on the expert role when the class wrapped-up the Whole Class Debate. At this point in the discussion, Mr. S took back control both in terms of managing speakers and the content. He did this by reading the teacher materials aloud, highlighting the reasons that each erroneous claim could not be true until he had disproved all but the correct claim. In this part of discussion, the focus turned back to Mr. S. Thus, it appeared that these students were willing to allow Mr. S to be the content-expert, even after they had performed as experts throughout their 33-minute debate.

Given the students' ability to shift from performing as experts who were able to evaluate and challenge competing arguments to performing as students who listened to and (largely) accepted their teacher's understandings, it is clear that, to the extent that these students had taken on the role of expert, they did so with the understanding that the teacher (and his materials) was the final authority. That is, the wrap-up discussion indicates that, while these students were able to act as experts, they accepted their teacher's implicit authority. The fluidity of authoritarian roles is a striking characteristic of the discussions in this classroom and one that I will explore at more length in future work. At this point, the students' acceptance of both the expert and student roles, can be interpreted as promising for curricular interventions designed to foster argumentative discourse: If, in fact, Mr. S' lack of expertise enabled these students to engage with one another's ideas, then the fluidity with which they both took up and relinquished that role indicates that they do not have to be the expert at all points in the discussion in order to engage in these social aspects of argumentation. Instead, it appears that one way teachers can facilitate substantive student-to-student interactions is to change the power dynamic of a classroom such that students are the perceived experts during the argumentative activity.

Thus far, this analysis has focused on understanding how the immediate learning environment in Mr. S' classroom enabled his students to frequently respond to one another's ideas. It suggests that he empowered them to interact directly with one another by putting them in the role of expert and minimizing his intervention. By minimizing his interactions with the students, Mr. S enabled them to respond directly to one another. Moreover, by putting them in the role of expert, he gave them a reason to attend to one another's ideas: The students had reason to believe that the teacher did not know the correct answer so it made sense for them to evaluate their classmates' ideas themselves.

This analysis leaves open the question of why Mr. S' students responded to one another in a manner consistent with critical or persuasive dialogue (Walton, 1998); why they evaluated whether they were persuaded and offered contradictory evidence without asking questions that enabled them to further make sense of one another's arguments. I explore that issue in the following section by examining whether and how Mr. S structured the content of the students' interactions.

5.3.2.1.2 How did Mr. S influence the content of the student-to-student interactions?

Mr. S introduced the first student presenter for the Whole Class Debate saying: "So, Joshua when you come up to present what are you going to use to make us believe that you are right?" He then followed this up with a brief discussion regarding the importance of justifying claims. Mr. S emphasized this point by saying: "[To convince us you are right] you have to have evidence, you have to have reasoning too, but you have to have evidence for that belief. If you believe it is rabbits likewise, you have to have evidence. Okay?"

In this way, Mr. S structured the students' contributions by explicitly stating that their presentations should contain a claim that is supported by evidence and reasoning. However, he did not communicate a similar level of expectations for how students should respond to one another. It is possible by telling Joshua to "make us believe," Mr. S was communicating that the role of the observing students was to *evaluate* whether they believed. However, this was the only presenter that Mr. S introduced by doing more than identifying the speaker, and, even if the framing did affect how presenters presented their arguments, the listening students had only an implied direction. That is, Mr. S never explicitly told students what their role was when they were not presenting their arguments. Moreover, given the brevity with which Mr. S mentioned the goal of persuasion, it seems unlikely that this resulted in his students picking up on it. Thus, it appears that there were other factors influencing the content of the students' responses to one another.

As discussed above, Mr. S' strategies appear to have influenced the students' discourse by enabling and empowering students to take control of the discussion and interact with one another. This freedom largely enabled them to engage with the activity in the way that made the most sense to them rather than in a way that aligned with the teacher's expectations. This combined with the lack of explicit directions regarding how students should interact means that the students could have engaged in the activity differently. For example, they could have asked one another more questions and evaluated each other less. Thus, I propose that the students' emphasis on evaluation grew out of other aspects of the classroom community—aspects of the ways in which the students and teachers interacted with one another and the scientific content when argumentation was not a focus of the activity. I examine this possibility in the following section.

5.3.2.1.3 How did existing ways of interacting influence Mr. S' students' argumentative interactions?

This analysis has identified key ways that the immediate learning environment created by Mr. S may have facilitated the high rate of student-to-student interactions and has revealed that these same strategies—giving students authority to control the discussion and enabling them to be the content experts—meant that Mr. S did not have a large influence on the content of the students' interactions (i.e., whether they questioned or evaluated one another). In this section, I extend analysis this by examining whether and how the existing classroom interaction patterns may have influenced these aspects of the students' argumentation. In particular, I focus on exploring the relationship between the existing classroom interaction patterns and the substance of the student-to-student argumentative interactions because the immediate learning environment—the curricular materials combined with the teacher's strategies—largely explains the frequency with which these occurred.

As discussed in Chapter 4, the tenor of the argumentative discussion in Mr. S' class suggested that, rather than focusing on understanding why they disagreed with one another, students were stating that they disagreed and justifying those evaluations (often with evidence that disproved a competing idea) in a competitive way. This emerged most clearly in the students' emphasis on evaluative statements: During the Whole class Debate, these students made about twice as many evaluative statements as they asked questions. Interestingly, this is consistent with how the students in this class responded to ideas throughout the *typical* interactions: During the typical discussions in Mr. S' class, 3% of the student utterances were questions while 22% were evaluations. This reveals that the discourse in Mr. S' class emphasized determining whether individuals agreed, over understanding why they (dis)agreed, regardless of the discussion type. In contrast, 10% of student utterances in typical class discussions in Ms. B's 2005 class were questions while 16% were evaluations (this is similar to the relative frequency with which students questioned and evaluated in Ms. B's 2005 argumentative discussions: 18% and 14%, respectively). This suggests that the relative frequencies with which students questioned and evaluated one another during argumentative discussions may have been influenced by the relative frequencies with which they did so during typical ones.

In addition to the consistency found in the students' contributions across lesson types, another contributing factor that may have led students to engage with one another's ideas in this competitive way was that the students were not prepared to reconcile their differences in any other way. That is, the literature suggests that students may struggle with reconciling their different opinions (e.g. Kuhn et al., 2000) and it does not appear that Mr. S modeled strategies for doing so. As discussed in Chapter 2, Mr. S frequently managed discussions in his class by identifying three or four students to answer a question and not evaluating the contributions until each of those students had shared their idea. After each identified student made a contribution Mr. S would evaluate all of the ideas. These evaluations typically used one of two criteria: whether the contributions matched information gathered from the students' reading, teacher guide or internet; or whether the majority of the students agreed with the ideas.

For example, during the eleventh observation of this class the students were discussing the characteristics of spiders. One student said that spiders have eight eyes. Other students disagreed with this claim and Mr. S said: "Maybe they do, but we're not all in agreement on that. So let's leave that one out to the side. Okay... It has to be something we can agree on" (Observation 11). During this exchange, the explicit rationale for rejecting the student's idea was not that it was factually incorrect but that the majority of students disagreed with it. Thus, it appeared that the criterion for "right" was whether most students agreed with it.

It is important to note that the emphasis on consensus seen in Mr. S' class discussion is qualitatively different from the goal of reaching negotiated consensus put forth by the Invasive

Species Whole Class Debate. That is, while the goal of reaching agreement was the same, the means were different: the Whole Class Debate was designed with the expectation that participants would negotiate their disagreements by engaging in lengthy evidence-based discussions about why they disagreed and incrementally reaching consensus by building on elements of one another's ideas with which they could agree. During the typical discussions in Mr. S' class, on the other hand, the disagreement was not discussed. Instead, a number of students would state an idea and the teacher would then determine whether enough of the students agreed with that idea to move on. If students did not agree Mr. S would either reject the idea (as he did in the spider example from above), or refer to an outside authority to resolve the dispute. For example, later in the spider discussion, Joshua and Darnell disagreed about how many body parts spiders have. Mr. S resolved this dispute by asking the teacher's aide to look it up online.

This move of resolving a dispute by either assessing whether the majority of students agreed with an idea or referring to an outside authority was consistent with how Mr. S responded to student disagreement, in general. This class engaged in only nine challenging episodes during the typical discussions I analyzed. These were instances in which one idea was directly challenged by a student or Mr. S. Joshua and Darnell's exchange regarding the number of body parts spiders have is an example of a challenging episode that occurred during a non-argumentative (i.e., typical) discussion. Seven of these nine episodes were concluded when the teacher stepped in to resolve the dispute, such as Mr. S did in the case of the number of body parts in a spider. In these seven episodes, Mr. S was not helping the students negotiate and resolve their different understandings. Instead, he provided an answer to the question. In contrast, as will be shown in Section 5.4, Ms. W frequently highlighted instances in which students disagreed with one another or the scientifically accepted answer and engaged them in a discussion in which they discussed interpretations of individual data points. These interpretations became small claims with which students could agree and, as such, became the fodder for negotiating agreement regarding the larger question at hand.

While the reconciliation strategies exhibited by Mr. S identified the scientifically correct answers (i.e., in the above examples, the students rejected the erroneous notion that spiders have eight eyes and learned that they had two body parts), they did not model how to negotiate differences. That is, rather than teaching students how to gather their own data, identify strengths in the ideas of a classmate, or admit weaknesses in their own, Mr. S' reconciliation strategies indicated that there was one right answer which could be identified by either having a majority of students agree upon it or an outside authority. This lack of modeling may therefore be one reason that students in this class responded to one another by evaluating rather than questioning contradictory ideas: students in this class evaluated and contradicted one another's ideas because Mr. S had not taught them how to negotiate their competing understandings in order to make sense of the phenomenon under study.

In summary, this analysis of Mr. S' classroom revealed that the immediate learning environment put students in positions of expert and therefore created opportunities for them to adapt the argumentative discourse in ways that made the most sense of them. These students made sense of scientific argumentation in terms of a "critical dialogue" in which they frequently responded to one another's ideas by evaluating and contradicting them. Examining this class' typical discourse reveals that this take on the practice is consistent ways in which students in this class typically interacted with one another and the ideas in this classroom: Students in this class consistently evaluated the ideas discussed more than they questioned them. Thus, in both the typical and argumentative discussions in Mr. S' class, students criticized one another but rarely built on one another's ideas. Finally, this analysis reveals that Mr. S may have influenced students' adaptation of this practice by frequently modeling that answers in science class would be accepted as correct when the majority of students agreed with them or they aligned with information from an outside authority. In this way, Mr. S did not prepare his students to negotiate their disagreements by discussing the strengths and weaknesses of each one.

5.3.2.2 Ms. B, 2005

Similar to Mr. S' class, about two-thirds of the student contributions during the Invasive Species Whole Class Debate in Ms. B's 2005 class occurred in the context of student-to-student interactions, rather than in response to a teacher prompt (this is discussed in more depth in Chapter 4). This meant that these students were frequently responding to one another's ideas. Unlike students in Mr. S' class, Ms. B's 2005 students attended to one another's ideas by asking one another questions more often than they evaluated one another. In this section I examine why students in this class engaged in argumentation in this way. I do this by exploring first how Ms. B facilitated the student-to-student interactions and second how the existing ways of interacting in Ms. B's 2005 class can explain this version of argumentation.

5.3.2.2.1 How did Ms. B facilitate student-to-student interactions in 2005?

Ms. B provided her students with much more support for the Invasive Species Whole Class Debate than Mr. S did. This support is described in Chapter 4 and included two key aspects that were adapted from work by Herrenkohl and Guerra (1998): 1) the students and Ms. B co-

constructed a list of questions they could ask one another during the Whole Class Debate. This was called the “Question Board.” 2) Ms. B identified three roles that students rotated through during the debate. These roles included presenters of arguments, questioners of arguments and silent observers. I illustrate the relationship between these scaffolds and the student participation in this section by showing how the scaffolds were used throughout the discussion.

Transcript 5.6 shows Ms. B using these two aspects of the lesson structure to introduce the first presenting group during the Whole Class Debate.

1	Teacher	Student[24], Sarah and Laura are going to present their answer to the question: "who is the, what is the invasive species." Peter and Toby are going to be their questioners. The rest of you are going to just observe. You're not going to say anything. But then you're going to get your turn in just a minute. Okay?
2	Teacher	So is everybody ready? The big ideas sheet[25] is behind the presenters. As are the questions, so that you who are asking questions or who are thinking about questions can be looking at them.
3	Teacher	Okay? Alright. Ready and go.

Transcript 5.6: Ms. B's introduction of the first group during the Whole Class Debate

Notice that in Line 1 of Transcript 5.6, Ms. B referred to the assigned student roles in order to communicate the students' responsibilities during the presentation: Sarah's group was responsible for presenting their argument, Peter and Toby were asking questions about it and the rest of the class was expected to remain silent. In the next line, Ms. B referred to the co-constructed list of questions to further communicate her expectations: questioners were expected to respond to the presenters' arguments by asking questions that come from, or were similar to, the questions listed on the Question Board.

The explicit roles of presenting and questioning influenced the ways in which the students argued by reducing Ms. B's need to manage the discussion. For example, at the conclusion of the first group's presentation, Toby, a questioning student, raised his hand. Ms. B responded to this by saying: "Okay, you guys don't have to raise your hands, you can just ask questions." Thereafter, the presenting students called on their questioners—reducing the need for Ms. B to manage the student-to-student interactions—or the questioning students called out

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[24] This student was not a consented member of the study.

[25] Throughout the unit this class created a list of "big ideas" that they were learning. For example, one "big ideas" could be the idea that animals compete for resources such as food, water and space. This list is the big ideas sheet to which Ms. B referred, here.

their questions. Moreover, these roles made students responsible for responding to one another. That is, unlike Mr. S who never explicitly described how the Whole Class Debate would work, the roles that Ms. B identified made clear when students would participate and the type of participation that was expected.

Over the course of the Invasive Species Whole Class Debate, the Questioning Board came to serve a similar function: It guided the content of the student interactions such that Ms. B did not have to. This transition is apparent when comparing Transcripts 5.7 and 5.8. Transcript 5.7 begins after Sarah's group defended their claim that the invasive species ate rabbits and could, consequently, be a snake. Following the presentation, Peter, a questioner, tried to disprove their claim by introducing counter evidence he observed in his own exploration of the simulated ecosystem. Transcript 5.7 shows Ms. B's reaction to this question.

1	Peter	We have taken tests and we have figured out that the invaders actually eat grass.
2	Peter	We don't think it could be a python, because those are strictly…
3	Sarah	Well our invader didn't eat grass
4	Teacher	Point of order, could you just look at the questions that are up there and try to ask questions like that, instead of saying what you found out. Okay?

Transcript 5.7: The first question posed to the first presenters in Ms. B's 2005 Whole Class Debate

As seen in Line 4, Ms. B responded to Peter's question by focusing his attention to the list of appropriate questions. Ms. B's scaffolds indicate that she did not want her students challenging one another by offering counter-claims and evidence, as Mr. S' students did: She wanted them focused on questions regarding the validity of the evidence and/or completeness of their classmates' arguments. Transcript 5.7 illustrates that, early in the Whole Class Debate, Ms.

B worked to accomplish this by using the Question Board to guide the ways in which students interacted.

Later in the discussion, students seemed to take over the use of the Question Board as a tool and Ms. B's explicit guidance faded. For example, Transcript 5.8 shows an exchange between a questioning student and a presenting student in which the questioners and presenter used the list of questions to negotiate the meaning of question.

1	Questioner 1	What were like your big ideas?
2	Presenter 1	What?
3	Questioner 1	Like what were your big ideas-because it says that big ideas were your bridge, but, like you didn't really say anything…
4	Presenter 1	Like what did we think was going to happen?
5	Questioner 2	What was the bridge?
6	Questioner 1	Like how does your evidence connect to your claim?
7	Presenter 1	Oh, how does the evidence connect with what we thought?
8	Questioner 1	Yea

Transcript 5.8: Illustrates a later exchange between presenters and questioners in Ms. B's 2005 class

In Line 1 of this exchange, Questioner 1 has paraphrased a question from the Question Board. The presenting students did not seem to understand her question and asked for clarification. In Line 3, Questioner 1 clarified her question by quoting the Question Board when she said: "…because it says…." The presenting students and questioners then exchanged a few possible interpretations of the question listed on the Question Board.

This example illustrates the way in which the Question Board became a tool that the students used to engage with one another's ideas: Not only did the Questioner 1 implicitly use it when identifying a problem with the presenters' argument (i.e., they had not used any big, scientifically accepted ideas to connect their claims and evidence) but she also used it to help the presenting students understand her question.

The way in which the Question Board influenced the students' discourse is also apparent in the teacher's lack of substantive participation. In Transcript 5.7, she corrected the first questioning students by telling them that the questions they asked should be similar to those on the Question Board and should not rely on contradictory evidence that the questioning students had observed. This is the only time that Ms. B made a correction like this. Thereafter, as exemplified in Transcript 5.8, student questions followed the example set by the Question Board, and Ms. B no longer explicitly guided the content of their responses to one another. Thus, the Question Board seemed to guide the content of the students' responses to one another: It focused students on questioning one another's ideas rather than emphasizing the evaluation and critique of ideas (as did Mr. S' students).

Given the ways in which the Question Board guided students to respond to one another in ways that met the teacher's desire (i.e., to ask questions) and the student roles managed who spoke when, Ms. B's primary responsibility during this Whole Class Debate was to assign student roles between each presentation (to facilitate the students' rotation through all of the roles) and to open the floor for questions at the conclusion of each presentation. Thus, it appears that the guidance provided by the Question Board enabled Ms. B's students to interact with one another because it communicated her expectations for these interactions while still minimizing her direct involvement in the discussion.

This analysis indicates that, in contrast to Mr. S, Ms. B maintained the position of authority throughout this discussion. That is, she began the discussion by providing the students with scaffolds to facilitate the student interactions, and this allowed her to guide how the students interacted with one another and the ideas. Even with this level of authority and guidance, Ms. B was able to minimize her role—thereby enabling students to interact with one another—by providing them with scaffolds that ensured they could meet her expectations while interacting with one another without her direct intervention. Thus, in both classes, reducing the teachers' roles such that students no longer needed to turn to them for approval or guidance seemed to facilitate their student-to-student interactions.

Combining the analyses of Ms. B and Mr. S suggests that the teacher does not have to give up all control and authority in order to foster student-to-student interactions. Mr. S' class paints a picture of a teacher who is truly unfamiliar—and this enabled students to be the content experts. Ms. B, on the other hand, created a structure that enabled her students to manage the discourse flow while using her authority to influence how students interacted with one another. She therefore provides an example of a way to give students control while continuing to guide the discussion.

5.3.2.2.2 How did existing ways of interacting influence Ms. B's 2005 students' argumentative interactions?

As discussed in Chapter 4, Ms. B's 2005 students engaged in argumentation as an information-seeking dialogue in which they frequently responded to one another's ideas by questioning them. The analysis presented in the previous section demonstrated that Ms. B's 2005 scaffolds might have facilitated the high rate of student-to-student interactions seen in this class. In particular, Ms. B gave her students explicit roles that made them responsible for responding to one another. Thus, similar to my analysis of Mr. S, I do not explore the relationship between the existing classroom ways of interacting and the frequency with which these students responded to one another during the argumentation: It is possible to explain their high rate of participation without looking to those typical patterns.

It is similarly possible to explain the content of the student-to-student interactions in terms of the immediate supports provided by Ms. B and the learning environment: The Question Board was used to focus students on questioning one another's arguments. In this way, it is possible that the existing classroom ways of interacting in this class had less of an impact on how students responded to one another in Ms. B's 2005 argumentative discussion than they did in Mr. S' class: Ms. B guarded against students turning the Whole Class Debate into a critical dialogue by guiding how they would interact. However, the emphasis on questioning seen during the Invasive Species Whole Class Debate in Ms. B's 2005 class is also consistent with students' utterances during typical interactions; students asked questions and evaluated ideas at equivalent rates both when argumentation was a focus of the discussion and when it was not (i.e., During the argumentative discussion 14% of the student utterances were questions and 18% were questions. During the typical discussions, these percentages were 10 and 16, respectively). Thus, it is possible that the typical ways of interacting in this class supported—or helped to prepare—students in engaging in argumentation as an information-seeking dialogue.

The analysis of Ms. B's 2005 class suggests that the supports and scaffolds provided by Ms. B were closely aligned with how the students adopted and adapted the practice of scientific argumentation. For example, Ms. B gave her students roles that highlighted the importance of student-to-student interactions and enabled her to minimize her role thereby providing them with opportunities to substantively engage with one another. In addition, she provided them with sample questions that guided how they responded to one another's ideas. Within this structure, the students' pre-disposition to ask questions was apparent in how they argued. Thus, while the teacher's scaffolds may have made it likely that students would argue in the ways that they did, it is likely that their existing emphases facilitated this form of argumentation. In this way, it appears that the typical ways of interacting in Ms. B's 2005 class aided in their use of the teacher's supports.

This analysis reveals that in both Ms. B's 2005 class and Mr. S' class the immediate learning environment explicitly fostered student-to-student interactions, but the way these played out—the content of the students' interactions with one another—was consistent with their existing classroom practices.

5.3.2.3 Ms. B, 2006

Ms. B's 2006 class stands out from the other two cases in which students engaged in a Whole Class Debate: While these students responded to one another more frequently during the argumentative lesson than they did during the typical, they responded to one another relatively less frequently than did students in either Ms. B's 2005 or Mr. S' classes. Thus, it appears that the Whole Class Debate activity structure somewhat facilitated an increase in student-to-student interactions (as it did in the other two classes), but that the characteristics of this learning environment (both in terms of the teacher's strategies and existing ways of interacting) may have resulted in students responding to one another less than students did in the other classes. The relatively low frequency of student-to-student interactions is made particularly interesting by the consistency in teacher: In 2006, Ms. B's students responded to one another's ideas less than they did in 2005. In this section, I explore how the immediate learning environment and existing interaction patterns differed in Ms. B's 2006 class in order to explain this variation.[26]

5.3.2.3.1 How did Ms. B facilitate student-to-student interactions in 2006?

In 2005, Ms. B structured the Whole Class Debate by explicitly providing students with roles that enabled them to facilitate the flow of the discussion and she heavily scaffolded the content of the students' interactions. Due to changes in the curriculum, she neither provided students with these roles nor obviously attempted to influence the content of the student-to-student interactions that did occur during the Invasive Species Whole Class Debate, in 2006. This lack of attention to the student-to-student interactions is seen in how Ms. B introduced the Whole Class Debate in 2006:

> Everyone turn around and listen to this group…. They're going to tell us what their claim is and what their evidence is for making the claim and then you may make comments or ask questions and you may make suggestions, or you may contrast what they're saying with something that you observed. But, you're going to do it in a very one-at-a-time friendly, polite way. Okay. [Turns to the presenting group] So go ahead, tell us what is your claim and what is your evidence?

In this introduction to the Whole Class Debate, Ms. B stated expectations for the content of the students' presentations (i.e., they must contain a claim supported by evidence) and she left the content of the students' responses to one another open. Thus, unlike her 2005 class—and similar to Mr. S—in 2006 Ms. B did not explicitly attempt to influence the ways in which her students responded to one another.

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[26] This analysis focuses solely on the frequency with which students in Ms. B's 2006 class responded to one another because the scarcity with which they did this means that it does not make sense to examine the content of those interactions—they made only 56 total utterances during the Invasive Species Whole Class Debate.

Moreover, instead of enabling students to manage the discussion by explicitly assigning students roles to play during the Whole Class Debate, she only addressed the possibility that students would manage the discussion once in 2006. She did this when the second group completed their presentation and she said:

> [To the class] Okay, so any questions, any questions for them, about what they saw?
> [To the presenters] Okay, you can call on people if anyone raises their hand.

By telling the presenting students to call on those students that had questions, Ms. B was apparently attempting to enable her students to take responsibility for the flow of the discourse. She was trying to remove herself from the interactions such that students could speak directly with one another. However, this did not happen. After this group called on the sole student with a question, the teacher introduced the next group of presenters and called on student questioners from there on out. Thus, in 2006, Ms. B played a more active role in managing the student discussion than she did in 2005.

Beyond managing the discourse flow, Ms. B facilitated the student presentations more actively in 2006 than she did in 2005. That is, as discussed in Chapter 4, she called on individual group members and prompted them to further justify the group's claim throughout the presentations. Of the three classes that engaged in the Invasive Species Whole Class Debate, this is the only one in which the teacher actively facilitated the content of the group presentations during the presentations themselves.

I hypothesize that the students in this class interacted with one another at a lower rate than did students in the other classes because they were neither afforded the opportunity to be experts (as were Mr. S' students) nor given the responsibility to manage the flow of the discussion (as were Ms. B's 2005 students). Moreover, it is possible that these students did not know what was expected in their interactions with one another and that, without being recognized as content experts, they were not willing to do what made sense to them (as did Mr. S' students). Thus, they may have responded to one another relatively infrequently because the immediate learning environment did not enable them to do so.

5.3.2.3.2 How did existing ways of interacting influence Ms. B's 2006 students' argumentative interactions?

Thus far, the analysis of Ms. B's 2006 class has indicated that she did not create strong expectations and supports for students to respond to one another's ideas. This raises the question: Why did her teaching practice change so drastically? I propose that this difference can be explained by examining both the typical class discussions in Ms. B's class and the support she received from the researchers.

One explanation for the change in Ms. B's teacher practice lies in the amount of support she received during the enactment, and the focus of that support. In 2005, Ms. B collaborated with another researcher and myself to design a pilot version of activities to facilitate student engagement in argumentative discourse. After reading articles and reportedly adopting our hopes regarding argumentative discourse, Ms. B helped refine the curriculum design—including the Whole Class Debate, student roles, and Question Board. In 2006, on the other hand, we provided Ms. B with a more solidified design and had fewer in-depth discussions about the goals of each activity. In addition, the materials we gave her in 2006 differed from the design she used in 2005. First, it suggested student-roles as a possible tool for facilitating student-to-student interactions but did not require them. Second, the Question Board Ms. B used in 2005 had been transformed into a list of guiding questions on the student sheets. Thus, in 2006, the supports that had been emphasized during design discussions were less prominent.

These changes to the curriculum and the support Ms. B received clearly account for some of her reduction in the activity scaffolds she provided her students. However, informal conversations with her indicate that her overall goals regarding how students interacted with one another's ideas remained consistent. Thus, this is not the whole story: Why did she not implement the strategies suggested by the materials, regardless of the level of support offered by the research team?

Considering the student differences—or typical interacting patterns—offers an alternative explanation. In an electronic-mail exchange that occurred in spring of 2007, Ms. B mentioned that the students in her 2006 class were finishing eighth grade and that teachers in the school found them to be "the most passive, lazy…group we have ever taught…. They lack intellectual curiosity, commitment, [and] drive. They are no fun at all." This lack of "intellectual curiosity" is apparent in the overall participation rate in Ms. B's two class: In 2005, Ms. B's students offered about 10 argumentative contributions per three-minute interval that occurred during typical class discussions, while her 2006 students offered only 7 in that same time period. Thus, it appears that, in general, Ms. B's 2006 students were less engaged than were her 2005 students. This may have resulted in her sense that she needed to facilitate the conversation more heavily than she did in 2005: She had to manage the flow of the discussion and prompt students to participate rather than giving them roles that enabled them to take responsibility for these actions.

I propose that this lack of active participation is one reason students in this class had the lowest relative frequency of student-to-student interactions during the Invasive Species Whole Class Debate: It appears that these students adapted both the activity structure and the teacher's supports to fit their predispositions for disengagement with classroom discussions.

5.3.3 How do the typical interaction patterns and Immediate learning environment facilitate the student-to-student interactions?

This analysis has identified two related strategies for facilitating the relatively high rate of student-to-student interactions seen in these classes:

1. Mr. S facilitated this high rate of interaction by enabling his students to be the content experts and giving them authority over the flow of the discussion. In this way, students had the freedom to interpret the task in ways that made sense to them. Moreover, this stance may have motivated students to attend and respond to one another's ideas because the teacher's lack of expertise meant that they could not turn to him for the answers.

2. In 2005, on the other hand, Ms. B heavily scaffolded the student-to-student interactions. This approach highlighted the importance of students responding to each other, and made them responsible for doing so. In addition, similar to Mr. S, this strategy gave students authority over the flow of the discussion: the explicit student roles meant that Ms. B did not have to manage who spoke when.

Comparing these strategies suggests that student independence and ability to manage aspects of the discussion may influence their willingness and/or ability to interact with one another's ideas substantively. Broadly, this finding suggests that it is likely that the immediate learning environment has a strong impact on whether and how frequently students respond to one another's ideas.

However, adding Ms. B's 2006 to the analysis indicates that these strategies must be used with care. In this class, the teacher did not try to implement one of these strategies. Instead, the teacher managed the discussion, calling on students during the presentations and prompting them to contribute the desired information (be it a question for the presenting group or a justification for the presenting group's claim). This raises the question: How would Ms. B's 2006 students have responded to the roles and question-board? It is impossible to answer this question with the current data set but it presents an interesting question for future research: Do these supports facilitate student-to-student interactions even in a class of students that show low levels of participation throughout typical class discussions?

This analysis has also indicated that the typical ways of interacting are apparent in the content of the students' responses to one another during the argumentative discussions. This is seen most clearly in Mr. S' class in which the students were enabled to respond to one another's ideas in ways that made sense to them and they did so by evaluating and criticizing one another. This emphasis on evaluation was consistent with the typical interaction patterns of frequently evaluating the ideas discussed. Moreover, the teacher did not model ways to negotiate differences of opinion. Similarly, students in Ms. B's 2005 class questioned and evaluated the ideas being discussed at equal rates during both the typical and argumentative lessons. Thus, it appears that the immediate learning environment might have had a direct effect on whether and how often these students respond to one another, while the existing interaction patterns might have had a large influence on the substance of those responses.

The above analysis has found ways that the typical ways of interacting combine with the immediate learning environment to facilitate and/or inhibit student-to-student interactions. In the following section, I continue exploring the relationship between these two aspects of learning environment by examining the successes and challenges that students had with revising their understandings in light of contradictory evidence and ideas.

5.4 EXPLAINING STUDENT SUCCESSES AND CHALLENGES WITH REVISION

Chapter 4 revealed that, during the argumentative lessons, students rarely revised their ideas as a result of interactions in which their ideas were challenged with contradictory evidence, disparate claims or questions. For example, students in Ms. B's 2005 class treated each other's arguments as stand-alone entities that did not need to be compared. In this situation, students had no reason to compare across arguments and revise their understandings in light of their classmates' evidence because they treated their arguments as though they were unrelated. Instead, these students engaged in an information-seeking form of argumentation. In Mr. S' class, on the other hand, students assumed that the arguments were related but they approached argumentative discourse as an opportunity to "win" by convincing others that they were right. Thus, students in Mr. S' class had no reason to revise their understandings as a result of their discussions—in fact this revision may have been counterproductive as it would have highlighted problems with their ideas. As discussed above, in 2006 Ms. B's students rarely responded to one another and, consequently, had little opportunity to exhibit revisions that grew out of those interactions. Thus, Ms. W's class was the only one in which students were likely to revise their understandings as a result of interactions in which new evidence and ideas contradicted their own. In this section, I explore how the immediate learning environment and existing ways of interacting facilitated this result.

5.4.1 How did the immediate learning environment influence students synthesizing?

Recall that, unlike the other three classes, the argumentative discussions in Ms. W's class were teacher-led. These discussions were designed to foster argumentation by asking students questions that had multiple plausible answers and providing them with evidence with which to resolve their disagreements. As discussed in Chapter 4, Ms. W facilitated these discussions by emphasizing the importance of evidence and repeatedly drawing students' attention to the evidence by asking them whether it supported their claims. I provided an explanation of how Ms. W facilitated this synthesis in Chapter 4. In this section, I review that support.

During one of the argumentative discussions, this class used a data table to determine what resources plants need to survive. At the beginning of the discussion all of the students agreed that plants needed sunlight and water but there was some disagreement regarding whether they needed soil. Ms. W supported her students in resolving this disagreement by helping them interpret the data in the data table. Throughout this discussion, Ms. W pushed her students to think about the larger question of what plants need to survive. To that end, their interpretations of the data became evidence to support their claims regarding whether plants could survive without soil. In this way, Ms. W guided her students as they made sense of the data, in order to construct claims that could be defended.

At the conclusion of this discussion the students still did not agree about whether plants need soil to survive. Ms. W then asked individual students why they disagreed with the claim that plants could survive without soil. Ms. W encouraged them to reconsider this claim in light of the available evidence, saying things such as:

> Right now, we are looking at a new set of evidence and if we are scientists we are constantly looking at evidence to see if our ideas are true or not true. So find the evidence… Find the evidence up here in this experiment to support your argument (Observation 13).

Ms. W offered similar supports when the class discussed whether the microscopic things they observed were living. In this discussion, students would report their observations and she would ask the class to help the reporting students to interpret those observations. The students would then have arguments about what qualified as evidence of life and Ms. W would draw their attention to their experiences with living things in order to resolve these questions. This support—this emphasis on the alignment between the available data and the students' claim—seemed to create a situation in which students were able to revise their understandings in light of the contradictory evidence.

5.4.2 How did the existing ways of interacting affect students' revision of their ideas during argumentative discussions?

As discussed above, Ms. W guided her students throughout the argumentative lessons in order to facilitate their synthesis of the data and ideas. Given her heavy facilitation, it is possible that the ways in which students in this class took up the argumentative discourse reflects the teacher's prompts more than their adaptations of the practice. However, as with Ms. B's 2005 class, it appears the typical interaction patterns may have helped Ms. W's students engage with her prompts during the argumentative discussions. In particular, students in Ms. W's class were more likely to explicitly revise their understandings during the typical discussions than were students in the other classes. This may have prepared them to do so during the argumentative lessons as well.

Transcript 5.9 provides an example of a challenging episode that concludes with a student revising his original claim during a typical discussion in Ms. W's class.

1	Ms. W	So what do we think now, Malcolm? What do you see, as an observer, what do you see?
2	Malcolm	The flowers are moving.
3	Ms. W	Okay, the seedlings are moving.
4	Ms. W	Okay. Are they moving on their own?
5	Malcolm	Yes
6	Ms. W	Okay. Are you coming over to our side of the argument?
7	Malcolm	Yes

Transcript 5.9: Example of challenging episode in Ms. W's typical class discussions that concluded with a student revising his original idea (taken from Observation 10)

The exchange shown in Transcript 5.9 is the conclusion of a challenging episode in which Ms. W challenged Malcolm's claim that plants do not move. She did this by playing a time-lapsed video that showed seedlings "moving" to point towards the sun. After showing the video, Ms. W asked Malcolm to evaluate his claim in light of this new evidence. In Line 7, Malcolm agrees that plants (at least some plants) can move.

During the typical class discussions, Ms. W's students averaged about one challenging episode for every two discussion segments that I analyzed, for a total of nine episodes. Five of those nine episodes were resolved when an idea was revised—similar to the exchange seen in Transcript 5.9. While these numbers are small, this is a striking result as ideas were revised through challenging episodes in only one other class (Ms. B, 2006). That class had a total of twelve challenging episodes, of which only two were concluded with a participant revising their understandings. Thus, while Ms. W's class provides only a small number of examples, comparing it to the other classes indicates that the pattern in Ms. W's class was different enough to suggest that Ms. W's students may have been more comfortable with the possibility that they could revise their understandings during challenging episodes than students in the other three classes were. This may help explain why they were able to do so during the days designed to foster argumentation.

This analysis of Ms. W's class indicates that the students were supported in synthesizing their ideas and the available evidence through two mechanisms: 1) Ms. W heavily facilitated this discussion, guiding them in doing this synthesis and 2) the typical interactions indicate that students in this class were more familiar with the practice of revising their understandings in light of contradictory evidence. Thus, like Ms. B's 2005 class, we see that the existing ways of interacting made it possible for students to engage with the scaffolds provided by the teacher during the argumentative lessons.

5.4.3 Why did students in the other classes rarely explicitly revise their understandings?

The previous analysis describes why students in Ms. W's class were able to synthesize the evidence in such a way as to facilitate the explicit revision of their ideas, but what about the other classes? Why is this explicit revision such a rare aspect of the students' discourse in the other classes?

One answer to this question is that no other teacher facilitated student revision through synthesis of evidence as explicitly as Ms. W did. In fact, no other teacher mentioned the possibility that students' ideas might change through the Invasive Species Whole Class Debate. Instead, these teachers introduced the debate as either a chance to "hear how other people interpret what is going on" (Ms. B, 2006) or "make us [the audience] believe that you are right" (Mr. S). Thus, synthesis of competing ideas was not an apparent focus of the activity.

Beyond the framing of the task and the teacher's facilitation, it appears that the three classes that enacted the Invasive Species Whole Class Debate (Mr. S's class and Ms. B's two classes), treated competing ideas during their non-argumentative (or typical) class discussions in ways that were consistent with students not revising their ideas. For example, seven of the nine challenging episodes in Mr. S' typical class discussions were concluded when Mr. S resolved the dispute by identifying the answer with which the majority of the students agreed or by using an outside authority to provide the correct answer. As such, students were rarely explicitly asked to revise their understandings in light of contradictory evidence. Instead the teacher assumed that they accepted his answer and moved on such that students were rarely in positions to admit the weaknesses in their understandings. This aligns with the students' adaptation of the Whole Class Debate, in which they rarely acknowledged weaknesses in their understandings or strengths in those of their classmates. Thus, it appears that these students were unable to resolve their disputes during the Whole Class Debate when the teacher did not do it for them.

In contrast, in both of Ms. B's classes the students occasionally ignored their disagreements during their typical, non-argumentative, class discussions. For example, in 2005, Ms. B 3 of the 12 challenging episodes identified in their typical discussions were ignored. In these situations a student would directly contradict an idea being discussed and no one would respond. The only other class to ignore challenges was Ms. B's 2006 class and they only did so in 2 of 11 challenging episodes. This lack of response is consistent with the lack of comparison and revision seen in the argumentation that emerged in both of these class. Recall that, during the Invasive Species Whole Class Debate, Ms. B's 2005 class treated each group's argument as an independent entity that did not relate to the other arguments discussed while Ms. B's 2006 did not respond to one another's ideas. In a sense, both classes ignored their disagreements.

The analysis of how the classes resolved their challenges during typical discussions reveals some striking consistencies across the contexts. Ms. W's students were the only ones to frequently revise their understandings in both contexts. Mr. S' students were unable to resolve their disputes during the Whole Class Debate, when he was not an active member of the discussion, and when he was an active participant (i.e., during the typical discussions), he resolved the disputes. Finally, in both of Ms. B's classes, the students were more likely to ignore their disagreements during their argumentative and typical discussions, than were students in any other class.

I suggest that these parallels are the result of epistemic commitments revealed by the typical discourse in each class. That is, the interaction patterns in each class communicated specific epistemic commitments during the non-argumentative discussions and these commitments carried over to the students' arguments. For example, in both contexts, Ms. W's students treated knowledge as something that they could construct and Mr. S' students treated it as something that was either right or wrong. Similarly, that Ms. B's students (in 2005 and 2006) largely ignored disagreements amongst themselves may indicate that they viewed scientific knowledge as something that their teacher evaluated and knew. This interpretation both explains why students in Ms. B's classes would find it acceptable to ignore one another's competing ideas and is consistent with the fact that the teacher resolved the majority of the challenging-episodes during the typical class discussions.

This apparent epistemic alignment between the typical interaction patterns and the ways in which students in each class responded to their disagreements indicates that one way to support students in revising their understandings through argumentative discourse might be to foster it during non-argumentative discussions. That is, helping students to accept the revision of ideas in light of new evidence as an important part of knowledge construction might help them engage in that aspect of argumentative discourse. This hypothesis indicates that if Ms. W's students had enacted a Whole Class Debate similar to the ones seen in the other classes, they would have continued to provide evidence of revising their understandings throughout the student-led discussion, without explicit teacher prompting. Without an example of that, this analysis indicates: 1) that students can revise their ideas in light of contradictory evidence when the learning environment supports it (both in terms of the immediate learning environment and the typical ways of interacting) and 2) the ways in which students respond to disagreements during argumentative lessons is affected by existing epistemic norms in the classroom.

5.5 DISCUSSION

The analyses presented in this chapter identify key ways that the immediate learning environment and typical interaction patterns influence classroom communities' adaptations of the practice of scientific argumentation. My analyses and this discussion focus on understanding why students defended their ideas; attended and responded to one another; and revised their understandings. These analyses have largely ignored the discourse aspects of constructing claims and participating in the discussion. I do not explicitly treat participation because it is implicit in the analyses of each of the other aspects of argumentation. I do not treat the students' construction of their initial claims because this is an aspect of argumentation that is present in all classroom discussions in which students are substantively discussing their ideas. Thus, I did not expect this discourse characteristic to exhibit differences when the typical and argumentative discussions were compared. Moreover, this study focuses on whole class discussions and the construction of that initial claim often occurs outside of whole class argumentative discussions. Thus, in this discussion, I look across the remaining three aspects of argumentative discourse—defense of ideas, attention and response to one another, and revision of ideas—in order to address the second research question of this dissertation: Why do classroom communities adapt scientific argumentation in the ways that they do?

I begin by synthesizing the analysis presented in this chapter in order to the relationship between the immediate learning environment and the students' argumentative discourse. This ensures that I do not over-attribute the influence of the typical interaction patterns in that it enables me to understand the context in which the argumentative discourse emerged. In addition, this question addresses the design research goals of this dissertation: Understanding how the immediate learning environment can influence students' argumentative discourse can inform future design endeavors.

I then move on to examine the relationship between the typical ways of interacting in each class and the students' argumentative discussions. The analyses already presented in this chapter relate the typical interaction patterns to students' work with the scaffolds offered by their immediate learning environment. For example, I found that the typical class discussions in Ms. B's 2005 class in which students frequently questioned one another might have been assisted in their work with the Question Board (a scaffold provided by the immediate learning environment). Thus, in that class, I found that the typical class discussions might have enhanced students' ability to work with the scaffolds. In this discussion, I reframe the question of how the typical ways of interacting influence students' argumentation by examining how the argumentative practice that emerged in each classroom was a composite practice that utilized aspects of their typical class discussions and aspects of scientific argumentation. Through this reframing, I elucidate both how the argumentative discourse in each class made sense in that context and how the typical discussions influenced students' argumentation.

I begin by examining the relationship between the immediate learning environment and students' participation in argumentative discourse.

5.5.1 How does the immediate learning environment influence student argumentative discourse?

The analyses presented in this chapter attempt to separate the influence of the curricular materials and activity design from that of the teachers' strategies. I did this by proposing that instances in which each class showed a similar changes in their argumentative and typical discourse could be attributed to aspects of the learning environment shared by all classes—the curriculum and activity design. For example, as discussed in Section 5.2, students in all four classes justified more than half of their ideas during argumentative discussions. Given the consistency of this result, I proposed that features of the curriculum—features of the learning environment that were similar across classes—could explain it. In contrast, when classes exhibited variation in how the argumentative lessons affected student discourse, I assumed that they were being influenced by their teacher's strategies and/or the typical ways of interacting in that class. For example, Ms. B's 2006 students responded to one another's ideas less frequently than her 2005 students and I attributed this difference to both a change in the teacher's strategies and a difference in the students' typical ways of interacting. In this section, I begin by combining my discussion of the each of the aspects of argumentative discourse examined in this chapter—defense of ideas, attention and response to one another, and revision—in order to identify ways that the curriculum might account for students' engagement in them. I then identify ways that the teacher influenced the students' argumentation during the argumentative discussion.

The IQWST curriculum used three strategies to support student participation in scientific argumentation:

1. *Making the epistemic criteria* explicit by providing students with an instructional framework to guide their construction of written arguments;

2. *Creating a need for students to use evidence* by constructing problem scenarios that had multiple plausible answers such that students had to use evidence in order to choose between these different possibilities; and

3. *Creating a need for students to argue* through activities that have a goal that can only be accomplished when students attend to the ideas of their classmates.

Given that the framework is introduced and used in numerous lessons—both argumentative and non-argumentative—its use during the argumentative lessons should not necessarily bring about a change in the students' discourse. That said, this framework was designed to encourage students to defend their claims and to provide them with information regarding how to do so. Moreover, McNeill et al. (2006) found that this framework supports students in justifying their claims when writing scientific explanations (or arguments). Thus, it seems likely that the instructional framework contributed to the frequency with which students did so during their argumentative discourse.

In contrast, the second and third design strategies were used most often and consistently during the argumentative lessons and it is therefore easier to attribute some changes in the students' discourse to these features of their learning environment. It appears that the second design strategy—creating a need for students to use evidence—may have facilitated students' in defending their ideas. All of the argumentative discussions analyzed were designed in accordance with this strategy, and all enactments of these discussions exhibited relatively high rates of justified ideas. Moreover, the IQWST team had posited that this strategy would facilitate the defense of ideas because it makes defending ideas a meaningful and useful task. That is, if there is disagreement, then participants have a reason to defend their ideas (de Vries et al., 2002). Thus, I hypothesize that this design strategy at least partially explains why students in all four classes defended over half of their ideas during the argumentative lessons. This conclusion aligns with a study conducted by Osborne et al. (2004) in which they examined the quality of students' spoken arguments when debating socio-scientific and scientific questions that had multiple plausible answers. These authors found that the students (across twelve classes) consistently defended their claims. This finding is further support for my conclusion that asking students questions with multiple plausible answers can create situations that motivate the defense of their ideas.

The rate with which students responded to one another does not seem to be explained by the use of this design strategy, because all four classes utilized this design strategy but students in only three classes responded to one another's ideas during the argumentative lessons more than they did during typical. Thus, the use of this design strategy is not paired with a consistent change in this aspect of argumentative discourse.

The final design strategy—creating a need for students to argue—was implemented in three of the argument lessons I analyzed. Students in each of these classes differed from the fourth in two ways: 1) they consistently offered more justifications during a three-minute interval during the argumentative lessons than they did during typical (i.e., each idea discussed received multiple justifications and counter justifications), and 2) they responded to one another's ideas directly more frequently during the lesson that created a need for them to do so—the Invasive Species Whole Class Debate—than they did during more typical lessons. That all of the classes that utilized this design strategy exhibited these characteristics and that the one class that did not use this strategy did not exhibit them suggests that creating a need for students to argue may have influenced both of these aspects of the argumentative discourse—both an increase in justifications and an increase in student-to-student interactions.

There are limits to this conclusion. For example, the argumentative activity was less successful at fostering student-to-student interactions in Ms. B's 2006 class than it was in her 2005 class. She partially attributed this difference to a difference in the typical classroom interactions in these classes: in 2005 her students were actively engaged in knowledge constructing, while in 2006 they were much less responsive. However, it is impossible to know how her 2006 students would have reacted to more supportive scaffolds, such as the ones she provided her 2005 students. Thus, I do not think that Ms. B's 2006 class contradicts this finding. It simply presents a limitation (Perhaps some classes of students will struggle with this regardless of the teacher's supports.) and a question (Can highly structured activity structures facilitate student-to-student interactions even in classes in which the students are typically disengaged?).

This analysis suggests that two aspects of argumentative discourse—defending ideas and attending to one another's ideas—were influenced through the design of the curriculum and activity structures. That is, the design strategies used had a similar effect on these aspects of the students' discourse, regardless of cross-class differences. However, students had less consistent success with the remaining aspects of scientific argumentation—including making sense of one another's arguments, evaluating and critiquing one another's arguments and revising arguments in light of contradictory evidence. Therefore, I conclude that individual class differences (including teacher practices and typical interaction patterns) may have more influence on these aspects of argumentative discourse.

This finding aligns with design research that has fostered student-to-student interactions by asking students to investigate questions with multiple plausible answers (e.g. de Vries et al., 2002; Hatano & Inagaki, 1991; Simon et al., 2006) and changing the goal structure such that students have a reason to engage with one another's ideas (e.g. Kolodner et al., 2003). However, it suggests that design research may over-attribute the affect of curriculum materials: While creating a need for students to defend their ideas and argue may facilitate in-depth student-to-student interactions that include the justification of ideas, given the impact of teacher strategies and typical classroom interaction patterns, this is not likely to be sufficient. Instead, if designers wish to influence *how* students respond to one another, than we need to do more than create these opportunities. That is, if we wish to influence whether students engage with one another by questioning and attempting to understand one another (as do Ms. B's 2005 students) or by evaluating and contradicting one another (as do Mr. S's students)—if we want to influence how students balance the goals of sensemaking and persuasion—than we must go beyond the supports available in curricular interventions. In the following section, I focus on how the teachers' strategies extended the curricular supports to influence these aspects of the students' argumentative discourse.

5.5.1.1 How does the teacher's practice impact student argumentation?

The analyses presented in this chapter suggest that teachers can directly influence whether and how students respond to one another's ideas. For example, in 2005, Ms. B supported student-to-student interactions by giving her students roles that highlighted the importance of these interactions. However, beyond the direct influence of teacher prompts and scaffolds, it appears that teachers also have an indirect impact on whether and how students respond to one another's ideas. Looking across the ways that Ms. W, Ms. B and Mr. S supported their students reveals three factors that were indirectly related to students' responses to the ideas being discussed.

1. The students' perceived expertise over the content being discussed, in relation to the teacher's expertise
2. The students' responsibility over the discourse flow
3. The degree to which the teacher structured the way in which the students responded to the ideas and evidence discussed

These elements of the teachers' supports were apparent in different combinations, in each of the classes analyzed. For example, in Mr. S' class, students had a high-level of perceived expertise when compared to the teacher (factor 1), and he did not structure the content of the students' interactions (factor 3). In contrast, Ms. W highly structured the students' interactions (factor 3), but gave them little responsibility over the flow of the discourse (factor 2) (i.e., she identified when students would speak and guided the content of their contributions). In this section, I discuss how these different factors of the teachers' strategies appeared to influence the students' argumentative discourse.

Using these dimensions to understand the frequency with which students responded to one another's ideas in Mr. S' class reveals that the students were the accepted experts in the domain being discussed; Mr. S was largely unfamiliar with the simulated ecosystem being used and called on his students to assist him in using it. Students in this class seemed to take this authority and build on it. For example, they frequently wrestled control of the discourse flow from Mr. S. In addition, this perceived authority seemed to give them permission to interpret the argumentative task in ways that made sense to them. And, for reasons that are discussed below, these students made sense of argumentation in terms of evaluating and contradicting one another's arguments.

In 2005, on the other hand, Ms. B explicitly discussed her expectations for how the students should interact. In this way, she was in charge of the students' contributions and, as such, she maintained the position of authority. However, the scaffolds she used enabled her to step back during the argumentative discussion and allow her students to manage who would speak when. Thus, her students were responsible for managing the discussion. In this situation, the students' authority over the discourse flow put them in positions to respond to one another directly while the teacher's scaffolds guided the content of these interactions. In contrast, Ms. B did not provide her 2006 students with these same scaffolds. This lack of support may have meant that her 2006 students were not empowered to take control of the discussion, which partially explains their relatively low rate of student-to-student interactions.

Combining across these dimensions highlights the importance of students having authority and responsibility over some aspect of the argumentative discussions for fostering student-to-student interactions. As stated by Jiménez-Aleixandre "Being in control is central for promoting argumentation…" (2008, p. 97). In Mr. S' class student authority over the content gave them the right to evaluate and question one another. In Ms. B's 2005 class, on the other hand, the student responsibility for the flow of the discussion made it possible for them to interact directly with one another. Ms. B's 2006 class and Ms. W's class, on the other hand, are both examples of discussions in which students had authority over neither the content nor the flow of the discussions. In fact, these students responded to one another's ideas relatively rarely. Consistent with this analysis and work by Cornelius and Herrenkohl (2004) and Tabak and Baumgartner (2004), I propose that giving students authority over some aspect of the discussion is a key aspect of students being able to substantively engage with one another's ideas. Table 5.1 summarizes this discussion of how teachers indirectly influenced the student-to-student interactions.

Table 5.1: Three proposed factors that influence student-to-student interactions

Teacher	Students' expertise over content	Students' responsibility over discourse	Teacher structures student interactions	Summary of student-to-student interactions
Mr. S	Students perceived more expertise than teacher	Students took responsibility from teacher	None	*Critical dialogue:* High student to student interactions in which they evaluated one another and presented competing claims and evidence.
Ms. B, 2005	The scaffolds provided by the teacher indicated that she was the authority over which contributions were acceptable	Teacher gave students a structure that enabled them to assume responsibility for the discourse flow.	Teacher highly structures the content of the interactions.	*Information-seeking dialogue:* High student-to-student interactions in which they questioned one another's arguments.
Ms. B, 2006	Student expertise was not an apparent part of the discourse, which results in a traditional image of the teacher as expert.	Teacher briefly asked students to take responsibility over the discourse flow but this did not last; she was responsible for the discourse flow for the majority of the Whole Class Debate.	None	*Information-sharing dialogue:* Low student-to-student interactions
Ms. W	Students were in roles to construct knowledge with the teacher, but the teacher was the accepted expert	The teacher controlled the discourse flow.	Teacher would occasionally ask students if they agreed with a classmates' ideas	*Inquiry dialogue:* Low student-to-student interactions

This analysis identifies ways that the teachers' strategies can go beyond the curricular materials to influence whether and how students respond to one another's ideas. The most striking factors of these strategies were those that had an indirect affect. That is, while explicitly prompting students to ask a question or evaluate an idea does influence how students participate, this data suggests that strategies that do this more subtly (i.e., the perceived expertise in Mr. S' class or the Question Board in Ms. B's 2005 class) may result in students having responsibility and ownership over aspects of the conversation and, consequently, it may facilitate a higher rate of student-to-student interactions.

5.5.1.2 EXAMINING THE RELATIONSHIP BETWEEN STUDENT ARGUMENTATION AND TEACHER PRACTICES

The discussion presented in the previous section, implies a one-way relationship between the teacher practices and student participation in argumentation: teachers set up activities and supports that students use as they participate in a scientific argument. However, as some of the above analyses suggest, the relationship is much more dynamic than that: teachers' strategies respond to the student participation while the students' participation is simultaneously responding to the teacher's strategies.

This co-creation emerges from the comparison of Mr. S' and Ms. B's 2006 classes. Mr. S tried to restrict his students' ability to manage the discussion. This is apparent in Transcript 5.5, in which Joshua and Mr. S negotiated who would control the discussion flow. In this exchange, it is clear that the students wanted to interact with one another directly, questioning and challenging one another's ideas, while Mr. S hoped to have a more structured exchange of ideas. In the end, this discussion fluctuated between a free-flowing exchange of ideas and a structured exchange in which the teacher identified the next speakers. Thus, the argument that occurred in this class reveals aspects of both the teacher's and the students' respective interpretations of the argumentative task.

In contrast, in 2006 Ms. B encouraged her students to control the discussion—she told the presenters to call on the questioning students at the conclusion of their presentation—but this did not occur. The observing students had few questions and the presenting students did not take on the responsibility of calling on those students that did have questions. Ms. B ended up following the students' lead and managing this discussion. Thus, in this class, the teacher's interpretation of the argumentative task changed to fit that of her students.

These two examples illustrate that students and teachers co-constructed the ways in which the classroom community engaged in the argumentative discourse. While the teacher attempted to facilitate specific types of interactions, the students controlled whether they followed this direction and the teachers responded to their students' reactions. This negotiation resulted in the argumentative discourse characterized in Chapter 4.

5.5.2 How was the argumentative discourse a composite practice?

The analyses presented in this chapter investigate why each class adapted the practice of argumentation in the ways that they did. This explanation compared the classes in order to understand how both the immediate learning environment and the students' typical ways of interacting with one another, the teacher, and the science content influenced their work with three aspects of the practice (defense of ideas, student-to-student interactions and revising understandings). Thus far in the discussion, I have focused on the ways in which the immediate learning environment can influence student argumentative discourse. In this section, I examine individual classes' adaptations of argumentation in order to understand the relationships between the immediate learning environment, typical ways of interacting and argumentative discourse, in each class. This discussion is grounded in the assumption underlying this dissertation: classroom communities adapt new practices to make them meaningful in the context of the practices of that community (e.g. Cobb, 2002; Engestrom, 1999; Lave & Wenger, 1991; Yackel & Cobb, 1996). Building on Hogan and Corey's work (2001), I call the resulting practice a "composite practice" because it reflects a combination of the aspects of the new practice and the aspects of typical classroom discussions.

I examine this assumption by discussing the "composite practice" that formed around argumentation in each class. In other words, I examine how the typical classroom culture in each class influenced students' argumentative discourse. In particular, I examine how the argumentation that occurred in each class made sense in the context of that class' existing ways of interacting. I do this by briefly reviewing how the students argued in each class and then identifying how aspects of that discourse relates to scientific argumentation and the typical discourse in that classroom.

5.5.2.1 The composite practice in Mr. S' classroom

Recall that, in Chapter 4, I characterized Mr. S' students argumentation as aligning with Walton's *critical dialogue* (Walton, 1998). In critical dialogue the goal is to prove one's own thesis to be true by identifying problems—criticizing—opposing arguments. Key aspects of critical dialogue in Mr. S' class included: students constructing and sharing ideas, students defending those ideas and students responding to their classmates' ideas by evaluating and contradicting them. This discussion differed from the arguments observed in the other classrooms in its emphasis on evaluation and contradiction. In addition, students in only one other class (Ms. B's 2005 class) responded to one another at a rate that was similar to the students in Mr. S' class. In this section, I explore why this version of argumentation—critical dialogue—made sense to the students in Mr. S' room. Doing so reveals how this discourse is a composite of the typical ways of interacting in Mr. S' class and those of argumentation.

In the analyses presented in this chapter, I found that the ways that Mr. S' students responded to one another's ideas during the Whole Class Debate largely aligned with how they interacted with one another, the teacher and the science content during typical class discussions. In particular, the argumentative emphasis on evaluating and contradicting one another without questioning their different understandings is consistent with their typical class discussions in which the students evaluated the ideas being discussed more than twice as often as they questioned them. In addition, there is alignment between the students' lack of synthesis during the Whole Class Debate and their typical class discussions: I hypothesize that these students were largely unable to reconcile their differences during the debate because the typical class discussions taught them that answers were accepted as correct when the teacher determined that majority of students agreed with it or when the teacher referenced an outside authority. Thus, it appears that the typical class discussions helped prepare students to respond to one another and handle their disagreements in the ways that they did, during their argumentative discussion.

Similarly, students in this class—and all classes—justified their ideas during both typical and argumentative discussions. Thus, it appears that the typical class discussions helped prepare students to engage in this aspect of argumentative discourse. In addition, students in the classes that enacted the Invasive Species Whole Class Debate (i.e., Ms. B's two classes and Mr. S' single class) all increased in the depth with which they justified their ideas—they all offered more justifications during a three-minute interval of argumentative discourse than typical. In the analyses presented in this chapter, I argued that the rate with which students justified their ideas increased because the activity structure and the questions being discussed created a need for students to defend their ideas. I therefore propose that students in Mr. S' class defended their ideas throughout their argument because it is an aspect of argumentative discourse with which they were familiar and, as discussed above, because it was a natural outcome of a discussion in which opposing ideas are discussed.

Finally, I found that students in Mr. S' class responded to one another's ideas during argumentative discourse more than students in two of the other classes—Ms. B's 2006 class and Ms. W's class—because of the immediate learning environment. This aspect of their argumentative discourse can be attributed to the Whole Class Debate activity structure and the perceived expertise of the students. Thus, this is one aspect of argumentative discourse that students seemed adopt because it made sense given the argumentative task, regardless of whether it fit within the existing ways of interacting in their class.

Combining the description of the students' argumentation with this understanding of their typical interaction patterns reveals that these students adapted the argumentative practice to fit within the context of their classroom by engaging in those aspects of the discourse that were either a discourse characteristic that the students frequently exhibited during typical discussions (i.e., evaluating and contradicting one another's ideas without reconciling differences) or an aspect that made sense given the problem context (i.e., defending ideas and responding to one another). In addition, these students struggled with the aspect that was in tension with their typical ways of interacting. In particular, these students neglected the revision of ideas because it did not make sense in the context of their classroom; it did not make sense in a community in which the teacher identified the right answer. Thus, in the composite form of argumentation found in this class, students engaged in key aspects of scientific argumentation (i.e., defending claims and attending to one another's ideas by evaluating them) but mirrored the class' existing epistemic criteria for determining correct answers.

5.5.2.2 The composite practice in Ms. B's 2005 class

Unlike students in Mr. S' class, Ms. B's 2005 students did not acknowledge their disagreements. Instead, their argument took the form of Walton's *information-seeking dialogue* (Walton, 1998) in which student participants asked one another neutral questions designed to extract more information about one another's ideas without evaluating them. This form of argumentation exhibited three key aspects of argumentative discourse: students constructed and shared their claims, defended those claims and attended to one another's ideas by trying to understand them. However, similar to Mr. S' students, Ms. B's 2005 students rarely revised their understandings in light of contradictory arguments, instead, they treated each argument as a stand-alone entity that did not need to be compared to the others.

As discussed in the previous sections, I hypothesize that students' familiarity with justifying their ideas facilitated their participation in this aspect of argumentative discourse. In addition, the complexity of their justifications was influenced by the complex question they were investigating and the Whole Class Debate activity structure. Thus, Ms. B's 2005 students enacted this aspect of scientific argumentation during argumentative discussion both because they knew how and because it made sense in the context of the immediate learning environment.

In contrast, I suggest that the relatively high rate of student-to-student interactions exhibited by Ms. B's 2005 students were more related to the immediate learning environment than to the typical classroom interactions. As discussed in the previous section, these interactions were supported both by the activity structure that created a need for students to respond to one another and Ms. B's additional scaffolds. In particular, Ms. B altered the activity structure to give students the responsibility of responding to one another and the students complied with this direction by doing so relatively frequently. In this way, the data suggests that students in this class took up a key aspect of the argumentative discourse because it made sense in the context of the activity and teacher's prompts.

In addition, it appears that Ms. B's 2005 supports guided student engagement such that their participation reflected her expectations as much or more than they reflected the typical ways of interacting in that class. This is seen when combining the teacher's insistence that students question one another's ideas neutrally and the finding that students in this class were more likely to question one another than were students in any other class. Thus, it appears that these students engaged in this aspect of argumentative discourse because it made sense in the context of the activity. However, examining the typical class interaction patterns reveals that students in this class asked questions relatively more often than students did in the other classes. Consequently, I conclude that, the typical interactions in this class prepared students to shift from evaluating one another to asking questions—to shift into classroom interactions that mirrored the teacher's expectations.

The students' response to their disagreements is the one way that the typical classroom interactions clearly influenced their argumentative discourse more than the activity structure.

Students in this class essentially ignored their disagreements and, instead, treated one another's arguments as stand-alone entities that did not need to be compared and reconciled. This is consistent with the ways in which students responded to one another's ideas throughout the typical class discussions: These students were more likely to ignore one another's ideas—to ignore challenges—than were students in other classes. I suggest that the students' tendency to ignore one another's ideas during typical class discussions aligns with their willingness to ignore their disagreements during the debate.

This analysis indicates that the composite practice that formed in this classroom was the result of a combination of the teacher's direction and typical classroom ways of interacting. In particular, the teacher guidance prompted students to break from their typical interaction patterns by increasing the frequency with which they interacted directly with one another, defended their claims and questioned one another. However, their response to the disagreement aligned more with their typical ways of interacting than it did with the practice of argumentation: That these students questioned one another neutrally without acknowledging their disagreement reflected the class' typical interactions in which the students ignored one another's ideas. In addition, this aspect of the students' argumentation differed from the expectation of argumentative discourse that participants will revise their understandings in light of one another's arguments. Thus, the composite practice that formed in Ms. B's 2005 class combined aspects of argumentative discourse, including students' making and defending claims and responding to one another's ideas, with the typical classroom norms of students treating one another's ideas as individual entities that do not need to be reconciled.

5.5.2.3 THE COMPOSITE PRACTICE IN MS. B'S 2006 CLASS

As discussed in Chapter 4, the dialogue that occurred during the Invasive Species Whole Class Debate in Ms. B's 2006 did not align with any of the anticipated argumentative dialogues identified by Walton (1998). Instead, students engaged in information-sharing in which they rotated through presentations of each group's argument and exhibited minimal attention to the presentations of their classmates. This pattern of participation reflected two key aspects of argumentative discourse: students constructed claims and defended those claims. These aspects of the discourse were made explicit in the prompts provided by the curricular materials and were made necessary by the activity structure of the Whole Class Debate. In addition, their lack of attention to one another's arguments mirrored the students' lower levels of participation throughout their typical class discussions. Thus, it appears that the students in this class made sense of the argumentative task by adapting it to fit within typical classroom interaction patterns: they followed the directions regarding the content of their presentations and did not substantially alter the ways in which they interacted with one another or the teacher.

5.5.2.4 THE COMPOSITE PRACTICE IN MS. W'S CLASS

Students in Ms. W's class engaged in what Walton calls an *inquiry dialogue* (1998) when they compared their claims to the available data and revised those understandings in light of the contradictory evidence. In this class, similar to the other three classes, the students constructed and defended claims. However, they differed from students in the other three classes in that Ms. W's students revised their arguments in light of the competing arguments but did not emphasize the importance of attending to one another's ideas. Thus, the interaction patterns in this class show students talking to the teacher much more than they respond directly to their classmates' ideas. In this way the composite practice formed in Ms. W's class revealed students engaging in aspects of scientific argumentation without substantively altering patterns in how they interacted with one another and the content.

For the other three classes, I argued that the typical classroom discourse prepared students to justify their claims and that the activity design and questions facilitated the increased depth of the students' justifications. While Ms. W's students defended their claims relatively frequently, they differed from the others in that they did not increase in the depth of their defense. As discussed above, this class also differed from the others in that the argumentative discussions did not use an activity structure designed to create a need for students to argue. I therefore suggest that students in this class justified their ideas because this discourse move aligned with their typical class discussions. I further suggest that the lack of an activity structure designed to create a need to argue partially explains why the depth of Ms. W's students' justifications did not increase during their argumentative lessons.

The argumentation in this class also differed from that of the other classes when Ms. W's students revised their understandings to align with the available evidence through the course of the discussions. This revision reflected the existing epistemic criteria found in Ms. W's classroom: throughout both typical and argumentative discussions, Ms. W asked her students how they could revise their claims so they could be supported by the evidence. Thus, the composite practice exhibited by Ms. W's class community reflected the expectation that ideas could be revised in light of one another's arguments.

However, these students were responding to teacher prompts and did not emphasize the importance of attending to the ideas of others. As such, the argumentation in this class rarely revealed students attending to one another's ideas. Instead, the interaction patterns in this class were similar to the interactions found throughout the typical discussions in this class: students responded to their teacher's contributions.

Thus, the argumentation that occurred in Ms. W's class largely reflected their existing ways of interacting. For example, the frequency with which students in this class justified their ideas, revised their understandings and responded to one another's ideas can be at least partially attributed to existing interaction patterns. The first two—justifying and revising ideas—resulted in discourse that aligned with aspects of argumentation while the third—infrequently responding to the ideas of others—resulted in discourse that differed from the expectation of scientific argumentation.

This analysis illustrates that the cross-class variation in student argumentation can be partially accounted for in terms of the variation in typical classroom communities. That is, this discussion demonstrates that classroom communities adapt new practices, such as argumentation, in ways that align with their typical ways of interacting—they make sense of the argumentative task by making it fit within their existing expectations. In addition, it shows that the lens of "composite practice" can be a useful way to understand how classroom communities take up new practices.

5.6 SUMMARY

In this chapter I have uncovered ways that curricular materials, teaching strategies, and existing interaction patterns each affect students' adoption and adaptation of scientific argumentation. In particular, it appears that the curricular materials have the most opportunities to influence whether students respond to one another and defend their ideas. The teaching practices can build on this by guiding the content of the students' interactions and empowering students to respond to one another at relatively high rates.

However, examining the composite practices formed in each class reveals that the ways that students make use of each of these scaffolds are influenced by the typical ways of interacting in each class. This relationship is apparent in Ms. B's 2006 class in which the pattern of students participating at low levels throughout class discussion seems to have inhibited their ability—or desire—to engage with the opportunities afforded by the curricular materials. That is, students in this class responded to one another and justified their ideas at lower rates than students in the other two classes that enacted the Invasive Species Whole Class Debate and this is consistent with the relatively low rate with which students participated during typical discussions in this class. Thus, it appears that the existing interaction patterns influenced how students engaged with the supports provided by the teacher and the curriculum.

Mr. S' class provides another example of this relationship: In this class, the teacher provided little guidance to the students regarding how they should interact with one another's ideas and, as such, he enabled students to make sense of the argumentative activity themselves. The sense that students made of argumentation in this class—their emphasis on evaluating and contradicting one another—aligned with the epistemic commitments communicated by existing classroom interaction patterns. Thus, the students' enactment of the activity structure was influenced by the typical ways of interacting in this class.

Finally, Ms. B's 2005 and Ms. W's respective classes provide an example of another way in which the existing classroom discussions influenced students adaptation of the activity structure and teacher scaffolds. In each of these classes, the typical ways of interacting prepared students to engage with the teachers' supports. For example, in Ms. B's 2005 class the typical classroom discourse emphasized the importance of students questioning and this aligned with her supports that guided how students would ask one another questions.

These analyses have uncovered strategies that teachers and curriculum designers can use to facilitate student participation in the various aspects of argumentation. In particular, this chapter reveals:

1. Asking students to investigate questions with multiple plausible answers and making the expectation that students will defend their ideas clear can facilitate this aspect of argumentative discourse.

2. Similarly, posing questions with multiple plausible answers and creating activities in which the goal of the activity creates a need for students to attend and respond to one another's ideas can facilitate this aspect of argumentation.

3. Providing students with authority during the argumentative lesson can enable and empower them to attend and respond to one another's arguments with greater frequency than the curricular materials alone.

As highlighted by Section 5.5.2, each of these strategies must be used with the understanding that the ways in which students typically interact with one another, the teacher and the science content impacts how they engage with the activity structures and scaffolds that support argumentation. In the following chapter I combine these individual findings in order to identify general ways that the non-argumentative—or typical—class discussions can influence the ways in which students adopt and adapt new practices. I then use this to identify pedagogical implications of this study.

CHAPTER 6: PUTTING IT ALL TOGETHER

As discussed in Chapters 1 and 3, the values that are communicated by traditional classroom practices can be in tension with expectations and goals of scientific inquiry. For example, Schwab (1962) has argued that a teacher's language unconsciously communicates a positivist view of science such that the students' goal is to learn the teacher's knowledge rather than to construct their own. This dissertation explores this disconnect by examining the relationship between the ways that students typically interact with one another, the teacher and the science content and the ways that students in these classes engage in scientific argumentation.

Hogan and Corey (2001) begin to address this relationship when they explain the challenges that fourth graders have with engaging in the scientific inquiry practices supported by the researchers' curricular intervention. These researchers found that the traditional goal of demonstrating individual success may explain the students' struggles with substantively critiquing one another's ideas. I extend their work by connecting the ways in which students take up a new scientific practice to specific ways that they typically interact rather than to the norms of traditional classrooms, writ large. In this dissertation, I do this by exploring the composite practice that formed when four classroom communities took-up the practice of argumentation, through the following two research questions:

1. How do classroom communities transform the practice of scientific argumentation?
2. Why do classroom communities adapt scientific argumentation in the ways that they do?

My analyses in Chapter 4 revealed that each class in this study adapted the practice of scientific argumentation differently. For example, Ms. W's students argued as a form of inquiry-dialogue while Mr. S' students did so as a form of competition. Regardless of the specifics of the adaptation, each form of the practice was internally coherent. For example, Mr. S' students critiqued and evaluated one another without asking many questions or revising their ideas. This take on argumentation is coherent because, if the students' goal was to "win the debate," then it would not have made sense for them to revise their own ideas in light of their classmates' ideas; doing so would have suggested a weakness in their ideas and a strength in those of their classmates.

In Chapter 5, I explained the variability that emerged in the argumentative discourse in each class by analyzing both the immediate learning environment (including teacher strategies and curricular supports) and the typical ways of interacting in each class. This analysis identified the "composite practice" that emerged in each classroom—explaining why each individual community adapted the argumentative practice in the ways that they did. This chapter concluded that the existing classroom interactions influenced the students' adaptations of the practice of scientific argumentation.

This finding aligns with work such as Spillane, Reiser and Reimer (2002) in which they characterized the ways that broad educational policies (i.e., standards based reform) get translated and interpreted in classrooms. In this work, Spillane et al. built upon the cognitive science literature to argue that teacher's construct their understandings of policy changes in terms of their existing understandings and beliefs about how students should and do learn and that it is these understandings that dictate the implementation of policies in classrooms. Moreover, these authors contend that

> …our usual approach to processing new knowledge is a conserving process, preserving existing frames rather than radically transforming them. New ideas

> either are understood as familiar ones, without sufficient attention to aspects that diverge from the familiar, or are integrated without restructuring of existing knowledge and beliefs, resulting in piecemeal changes in existing practice (Spillane et al., 2002, p. 398).

In other words, one would expect teachers to adapt new educational policies so as to enable them to minimally change their teacher practices.

My work extends that of Spillane et al. in two ways. First, I view reform curricula—such as IQWST—as a vehicle for communicating policy. In the case of IQWST, one could argue that the units communicate policies regarding what content students should learn and how they should do so. Second, I shift the analytical focus from “teacher” to “classroom.” That is, rather than examining the teacher’s adaptation of the “policy” of engaging in the practice of scientific argumentation, I focus on how the classroom community adopted and adapted this policy. This shift is warranted both by the data in this study (e.g., Chapter 5 provides examples of the students and teacher co-constructing their interpretation of this practice), and by the expectation that argumentative discourse will enable students to become active participants in the knowledge construction process: If one expects students to actively participate and therefore drive some of the discussions, than they will be interpreting the argumentative practice with their teacher (Cornelius & Herrenkohl, 2004; Tabak & Baumgartner, 2004). In this view, Spillane et al.’s (2002) argument suggests that the classes that participated in this study would make sense of the practice of argumentation through a process of adopting those aspects of the practice that are familiar and adapting the others to fit within existing ways of interacting.

In this discussion, I extend this conclusion by examining the practical implications: If the existing classroom practices influence the way students’ adopt and adapt new practices, then how can educators facilitate students in taking up new practices? How can educators help students make sense of the "policy" of engaging in the practice of scientific argumentation? I begin by reviewing the results of the analyses presented in this chapter with a focus on understanding which aspects of the existing classroom practices influenced the students' argumentative discourse.

6.1 THE PARTICIPATING CLASSES' ARGUMENTATIVE PRACTICE

The literature reveals many ways of treating the construct that I am calling a "classroom practice." For example, Warren and Rosebery (1996) describe the "discourse of science" as including the sociohistorically constituted strategies and criteria for developing knowledge, evaluating knowledge claims, and arguing for theories. These authors envision science classrooms as places in which students appropriate these epistemic strategies and criteria. Yackel and Cobb (1996) discuss the "classroom processes" that are made up of social norms, sociomathematical norms and classroom mathematical practices. In other words, Yackel and Cobb highlight the expectations about who talks and the kinds of activities that are done, the classroom norms regarding the types of answers that are valued (similar to Warren and Rosebery's constructs), and the mathematics skills. Similarly, Tabak and Baumgartner (2004) discuss students' understanding what they are doing, why they are doing it and how to do it.

Building upon these authors, I defined a practice in Chapter 1 as an activity that entails goals (i.e., why participants are doing something), interaction patterns (i.e., social norms) and epistemic commitments (i.e., sociomathematical norms or criteria for developing and evaluating knowledge) upon which the community members tacitly agree. For this discussion, I broaden the category of "epistemic commitments" to encompass beliefs about science and learning, more generally. Future studies focused on the mechanisms that enable existing classroom practices to influence students' adaptations of new practices may find the distinction between beliefs and epistemic commitments useful. However, for this discussion, the broader category enables me to discuss multiple aspects of the students' interactions rather than the epistemic ones alone.

Table 6.1 summarizes the characterizations of the classroom discourse that I provided in Chapters 4 and 5 in terms of the goals and beliefs suggested by the interaction patterns in which the students engaged.

Table 6.1: Goals and beliefs revealed by the interaction patterns of each class' argumentative and typical discussions

Teacher / Lesson Type	Goal of class discussions	Epistemic commitments and beliefs	Interaction patterns
Mr. S Typical	Demonstrate that students know the right answer	• Science ideas are either right or wrong • The teacher does not necessarily know the right answer • The idea with which the most students agree is assumed to be correct • Students can challenge the ideas	• Students present and defend their ideas • Students are eager to contribute • Students evaluate ideas • Mr. S evaluated ideas based on agreement and/or an outside authority • Differences are reconciled by teacher or outside authority
Argument	Critique others' ideas to demonstrate that they know the right answer	• Students can figure out the right answer (plus the typical beliefs and epistemic commitments)	• Students respond to one another • Students evaluate and critique ideas • Differences are not reconciled

			(plus the typical interaction patterns)
Ms. B, 2005 Typical	Learn their teacher's understanding	• The teacher knows the right answer	• Students present and defend their ideas • Students question ideas • Teacher frequently follows tangentially related science ideas • Disagreements are occasionally ignored
Argument	Learn their classmates' understandings	• Students should not challenge one another (plus the typical)	• Students question ideas • Students respond to one another • Students ignore their disagreements (plus the typical)
Ms. B, 2006 Typical	Derail the discussion and/or make classmates laugh	• The teacher knows the right answer	• Students present and defend their ideas • Students productively participate less frequently than students in other classes • Students phrase contributions in a humorous manner • Teacher frequently follows tangentially related science ideas
Argument	Share ideas	• The students' role is to fulfill the teacher's requests (plus the typical)	• Relatively low rate of student-to-student interactions (plus the typical)
Ms. W Argument and Typical	Interpret data in order to construct knowledge.	• The right answer is the one that best explains the data • Students can	• Students present and defend their ideas • Students present and defend their ideas • Relatively low rate of student-to-student

		figure out the right answer • Students can challenge the ideas	interactions • Students frequently discuss the data and their interpretations of it before defending their claims. • Students challenge the ideas being discussed, regardless of author • Students revise their ideas in light of contradictory evidence

Table 6.1 summarizes the analyses I presented for each class in Chapters 4 and 5 by identifying the goals, epistemic commitments and beliefs, and interaction patterns that emerged during both the typical and argumentative lessons in each class. Recall that the analysis in Chapter 4 used the interaction patterns to characterize the ways in which students engaged with the goals of sensemaking, articulating and persuading. These are instructional goals in that they are reasons an educator may want students to engage in an argument. However, they do not speak to the students' interpretations of the task. In contrast, the goals I identified in Table 6.1 speak to the students' and teacher's apparent goals for engaging in the class discussions. I inferred these goals based on the interaction patterns seen in each class. For the argumentative lesson, in particular, the goals grow out of the application Walton's (1998) taxonomy of argumentative dialogues presented in Chapter 1.

The middle column in Table 6.1 identifies the epistemic commitments and beliefs that were revealed by the interaction patterns that emerged in each class. For example, recall that during the Whole Class Debate Ms. B's 2005 students agreed that they were investigating different questions. This decision was both made explicit at the conclusion of the discussion and was apparent in the neutral way with which these students questioned one another and responded to those questions. Given these interaction patterns, I concluded that these students believed that they should not challenge one another's ideas—that respecting one another's contributions entailed finding a way to allow them to have disparate ideas. Note that the goals, epistemic commitments and beliefs identified in Table 6.1 are not an exhaustive list. Instead, these are the goals, beliefs and epistemic commitments that the interaction patterns on which my analyses focused.

Using these entities—goals of the class discussions, epistemic commitments and beliefs, and interaction patterns—to understand the relationship between a classroom's existing practices and their adaptation and adoption of the practice of scientific argumentation suggests that the interaction patterns are more easily shifted during argumentative discussions than the goals and beliefs. In other words, the students' argumentative discourse reflected the goals and beliefs of the existing classroom practices much more strongly than they did the interaction patterns. For example, the interaction patterns in Mr. S' class shifted from the typical classroom discussions to the argumentative one: the students interacted with one another directly more frequently during the argumentative discussion. However, the beliefs and goals apparent in this class were largely consistent across the two lesson types. That is, the interaction patterns during the typical discourse indicated that the students were foregrounding the goal of demonstrating that they knew the right answer. During the argumentative lesson, these students continued to focus on this goal—they demonstrated their own accuracy by critiquing their classmates' arguments. There is a similar consistency across the epistemic commitments and beliefs in this class. In fact, the epistemic commitments of the argumentative lesson mirrored those of the typical class discussions with the addition of one new one: during the argumentative lesson, the discourse suggested that the students thought they could figure out the right answer. While a shift, this new epistemic commitment is consistent with those of the students' typical discussions. That these students thought they had the ability to figure out the right answer during the argumentative lessons is consistent with the view that the teacher did not necessarily know the right answer and that the students could challenge the ideas being discussed. Thus, in this class, the argumentative discourse in which the students engaged appears to be largely influenced by the existing classroom practices.

Each of the other classes that participated in this study reveals a similar pattern: the goals and beliefs of the existing classroom practices can be seen in how the students adapted the practice of scientific argumentation. This is most obvious in Ms. W's class, in which the two lesson types resulted in near identical discourse. In Ms. B's 2006 class, the students' apparent goal shifted from making their classmates laugh during typical discussions to following their teacher's prompts during the Whole Class Debate. While a shift, both of these goals suggest similarly low levels of student engagement in knowledge construction. Finally, in Ms. B's 2005 class we see a consistency in their goal as it shifts from learning from the teacher to learning from one another. In both cases they attend to and question the speaker (teacher or student), but in neither case do they evaluate and critique the ideas being discussed.

These comparisons reveal that, in each class, the students' interpretations of the argumentative activity were influenced by their existing classroom practices. This raises the question: What can we do about this? How can we support student adoption and adaptation of new practices if they are influenced by the typical practices in a class? I discuss this question in the following section.

6.2 HOW CAN EDUCATORS SUPPORT STUDENT ENGAGEMENT IN SCIENTIFIC ARGUMENTATION?

I began this dissertation by asking the broad question: What composite practice forms when students engage in the practice of scientific argumentation? In exploring this question, this study revealed that students used the goals and beliefs that guided typical classroom practices to interpret the activity structures for and teacher's framings of the new practice of scientific argumentation. That is, the composite practice that formed combined the opportunity and expectations communicated by the immediate learning environment (teacher's framing and activity structures) with the beliefs and goals that students typically brought to bear on their classroom interactions.

This conclusion explains why teaching techniques that may be designed to change classroom practices, such as the use of manipulatives in a math class, can have such varied results in classroom enactments (Ball, 1992): each classroom differentially makes sense of the resources and activity structure, based on their existing classroom practices. In other words, the opportunities created by the math manipulatives do not necessitate that classroom communities change their beliefs and goals. Instead, they can use these tools in ways that align with their existing beliefs and goals. Thus, interventions such as interactive technologies or new curricula face challenges in confronting existing classroom practices (e.g. Ball, 1992; Spillane et al., 2002).

Similarly, the conclusion that classroom communities will interpret the opportunities and expectations created by their teacher and activity structures underscores the importance of systemic approaches. For example in their work with Fostering Communities of Learners (FCL) Brown and Campione (1996) argue that classroom communities must use the entire FCL system rather than select individual activities. In terms of the study presented in this dissertation, selecting individual activities may create opportunity and identify expectations for particular practices, but it would not change the students' beliefs and goals. In these situations, students could meet the expectations articulated by the teacher and supported by the activity structure but do so to very different ends. For example, as seen in this study, students could respond directly to one another's ideas in order to critique them, question them or synthesize across disparate understandings.

This work raises the question: If students will interpret the activity structure and teacher supports in light of their existing beliefs and goals, how can designers and teachers support students (and teachers) in taking on the beliefs and goals that align with new practices? I propose that teachers and designers can address this challenge by taking seriously the assertion that beliefs and goals are *communicated by* the interaction patterns in which students engage (Brilliant-Mills, 1994, p. 301; Floriani, 1994; Green & Dixon, 1994; Heras, 1994). This language suggests that engaging in particular interaction patterns may help students take on goals and beliefs that align with those interactions. Thus, the question becomes: How can teachers and designers scaffold students such that the students' engagement new interaction patterns facilitates their use of beliefs and goals that differ from those of their typical classroom interactions?

I propose three strategies to facilitate students' meaningful participation in interaction patterns that align with the goals and beliefs of new practices, such as scientific argumentation:

1. Create opportunities for interaction patterns via activity structures
2. Explicate the expectations for how these interactions will occur through teacher supports and framing
3. Create a need for the beliefs and goals that align with the desired interaction patterns

Taken individually, or even used together one time, these strategies will result in limited success: as seen in this study, students will interpret the situation created by these scaffolds through the lens of the beliefs and goals that align with their typical classroom practices. Thus, the power in these principles comes in their combined use, over time. That is, when done often enough the expectations and opportunities created by these design strategies will become increasingly sensible as they will become the norm—they will become the typical way of interacting and therefore become the lens through which students interpret the opportunities and expectations created by the immediate learning environment for future practices.

In the following sections, I describe each of these strategies and provide examples of them from the classes that participated in this study.

6.2.1 Create opportunities for interaction patterns via activity structures

In both Mr. S' and Ms. B's 2005 classes, the students changed their interaction patterns from their typical to argumentative lessons—they increased the rate with which they responded to one another. In addition, in both of these classes, the Whole Class Debate activity structure was enacted in a way that created opportunities for the students to do so: Mr. S did this by physically stepping back such that he was no longer in the position to lead the discussion, while

Ms. B did so by explicitly assigning student responsibilities thereby enabling them to manage the discussion flow (details about these strategies are presented in Section 5.5). This provides some evidence that simply changing activity structures can result in a change in the interaction patterns that students enact.

These two classes suggest that students will frequently do what they are asked to do: if you design activity structures that enable student-to-student interactions they will respond to one another. However as seen in the breadth of ways that students responded to one another across the classes, these activity structures provide only limited guidance regarding the substance of the students' interactions. They therefore provide few cues to help students make sense of the practice. For example, creating a space for students to respond to one another enables student-to-student interactions without helping them to determine whether they should be evaluating and critiquing their classmates or synthesizing across disparate understandings. The following two sections present strategies for influencing these deeper aspects of the students' engagement in new practices.

6.2.2 Explicate the expectations for how these interactions will occur through teacher supports and framing

The second strategy is to explicate details regarding how the new practice will work. This strategy goes beyond creating opportunities for a specific type of interaction (i.e., student-to-student interactions) through activity structures by making expectations regarding the substance of their interactions and the students' processes for engaging in the new practice of scientific argumentation explicit.

The roles and guidance provided by Ms. B in 2005 are one way to do this. Before the debate began in this class, Ms. B worked with her students to identify questions that they could ask one another during the Whole Class Debate. Then, during the debate itself, Ms. B encouraged her students to use these questions when responding to one another and explicitly asked them not to critique one another's ideas. Ms. W also guided the content of the students' interactions when she consistently pushed them to use evidence to support, evaluate and revise their own ideas as well as the ideas of others.

In both of these classes, the students complied with the teacher's requests—asking questions and using evidence respectively. However, this success must be accepted cautiously. The idea of clearly delineating the expectations regarding the content of students' interactions removes their ownership: Rather than interacting to achieve a sensible goal, the students can now interact to fulfill a script provided by their teacher. Indeed, examining the students' questions and non-verbal cues during Ms. B's 2005 Invasive Species Debate suggests that some of her students were following her guidelines without buying into the underlying beliefs and goals. This is seen when students read questions verbatim off of the sample questions provided by Ms. B while rolling their eyes or sounding uninterested. These behaviors suggest that some of the students used the teacher's guidance as a script, rather than as clues regarding the goals Ms. B had for their engagement in the activity. In contrast, Ms. W's students met her expectations in ways that seemed more connected to her goals: they appeared to be using her focus on evidence to answer the questions rather than as a requirement they must meet. I suggest that Ms. B and Ms. W's students reacted to these scaffolds differently because of the teachers' their differential implementation of the third strategy: creating a need for the beliefs and goals that align with the desired interaction patterns. The following section describes this final strategy.

6.2.3 Create a need for the beliefs and goals that align with the desired interaction patterns

In Section 6.2.1, I suggested that activity structures could create opportunities for particular interaction patterns—as seen in this study in which the Whole Class Debate activity structure facilitated student-to-student interactions. In Section 6.2.2, I argued that teacher scaffolds could influence the substance of the students' contributions and their processes for engaging in scientific argumentation. The enactments in this study demonstrate that these strategies facilitate students in taking up new interaction patterns. In this section, I look to the third design strategy—creating a need for the beliefs and goals that align with the desired interaction patterns—to facilitated students interpret the opportunities created and expectations explicated by the first two strategies. In other words, this final strategy is designed to help students take up the beliefs and goals that align with the interaction patterns supported by the first two design strategies.

In Chapter 3, I defined the strategy of "creating a need." This design strategy is built on the conjecture that aspects of the immediate learning environment—the explicit goal of an activity—could meaningfully affect the goals that students have going into the discussion, thereby impacting their beliefs and interaction patterns. In this section, I explore the whether and how argumentative discussions in each class created a need for students to reach consensus by synthesizing their disparate ideas. This discussion identifies ways that this final strategy may be a solution to the design challenges raised by Sections 6.2.1 and 6.2.2.

Ms. W's class offers an example an instance in which the goal of the activity aligned with desired interaction patterns, beliefs and goals. The participants (students and teacher) in this class were working together to interpret data. This goal aligned with interactions in which participants questioned the ideas being discussed, compare them to data and offer evidence to justify their own claims. Thus, the characteristics of the students' argumentative discourse aligned with the teacher's desired goal. Moreover, these goals and beliefs aligned with the existing classroom practices—the students did not need to change their interaction patterns or their beliefs and goals in order to engage in the argumentative lessons.

In contrast, students in Ms. B's 2005 class were enacting an activity structure designed to create a need for consensus building (Whole Class Debate). However, as discussed above, the characteristics of the students' argumentative discourse in this class aligned with her scaffolds (they questioned one another but did not critique disparate ideas) but not with the goal of consensus building. In fact, by focusing on the teacher's guidelines, these students appeared to interact with the goal of satisfying her requirements, regardless of whether those interactions aligned with the goal of consensus building. Had the activity been designed such that the students' questions of one another served a clear purpose than their interactions may have felt more authentic and less "script-like."

Similarly, the process of synthesizing across disparate understandings to reach consensus during the Whole Class Debate in Mr. S' class had no value for the students. While students were asked to reach consensus, their final assignment was to individually write-up their understandings, regardless of what their classmates had said during the discussion. Thus, students had no real need to identify strengths in their classmate's ideas and synthesize across their disagreements. Instead, they were able to interpret this discussion as they interpreted many school discussions: as an opportunity to demonstrate that they know the write answer—to compete.

Finally, in Ms. B's 2006 class, we see that the goal of consensus building did not make sense given the students' existing ways of interacting. In this class the teacher provided the students with an activity structure designed to give them an opportunity to respond to one another's ideas. However, recall that the students in this class responded to one another's ideas at particularly low rates, when compared to the other classes that enacted this activity structure. Examining their existing classroom culture reveals that these students were often more focused on making their classmates laugh and distracting the conversation than they were on substantively engaging in the discussion. This goal of distracting the conversation suggests that the students typically believed that ideas in science class were uninteresting which aligns with their lack of engagement during the Whole Class Debate. In this way, it appears that the beliefs and goals with which the students' typically interacted inhibited the students' ability to take advantage of the opportunities provided by the argumentative activity structure.

This analysis suggests that a key factor in how much a learning environment will influence the students' interaction patterns, beliefs and goals is how similar the desired beliefs and goals are to the students' typical practices. If they greatly differ—such as was the case in Ms. B's 2006 class in which the students were asked to shift from believing the ideas discussed were uninteresting to valuing and responding to one another's ideas—their ability to take advantage of the activity structure and scaffolds provided by the teacher will be limited. However, if these scaffolds are prompting interaction patterns that align with goals and beliefs with which the students are familiar, they will experience more success. Moreover, the more closely the desired beliefs and goals align with the students' typical ways of interacting, the more the students will be able to engage in the desired interactions as a way to accomplish a goal, rather than as a script to follow.

I therefore suggest that the challenges seen in Mr. S' and Ms. B's respective classes could be addressed through two nuances to the 'create a need' design strategy. First, the outcome of the activity must align with the desired goals and beliefs and second, the goals and beliefs will be easier to engender if they align with (or are similar to) existing classroom practices. As discussed earlier, this means that fostering student engagement in new practice requires that immediate learning environments follow these three design strategies repeatedly such that the goals and beliefs that align with the new practice—that align with the new opportunities and interactions being fostered—become the norm. In this way, the goals and beliefs of the new practice will gradually infuse the students' discourse and become the lens with which students interpret activity structures and teacher scaffolds.

6.3 LIMITATIONS AND FUTURE WORK

Is it fair to expect conclusions to relate to other classes and other scientific practices? In other words, how confident can we be of these findings and how generalizable are they?

This study used discourse analysis to explore the classroom discussions of four classes. One large limitation that faces this study is my ability to interpret the speakers' utterances. That is, the claims I have made throughout this dissertation rest on numbers generated by coding the transcripts of classroom discussions. Thus, if the coding process misinterpreted the speakers' intentions then the resulting analyses would be inaccurate. A common response to this challenge is to use multiple coders and assess the degree to which they agree in their interpretation of the utterances. This technique would ensure that the coding process was applied consistently. However, this technique would not address the larger challenge of assessing whether the codes themselves were able to capture the interesting variation and identify authentic patterns in the classroom discourse. Loucas and Hammer (in review) suggest an alternative approach to validating a coding scheme: providing detailed descriptions and transcripts throughout the data discussions in order to allow readers to assess whether the patterns being discussed were reflected in the classroom discourse. This was the path used in this dissertation.

A related challenge of this study is that of using the phenomenology—the classroom discourse—to identify classroom norms. Ideally one would address this challenge by triangulating interpretations of the classroom discourse patterns with student and teacher interviews. Given that the interview data in this study did not facilitate these analyses, I focused on identifying interaction patterns, only occasionally using the interviews to speculate about the norms underlying the interaction patterns. Future studies with more robust interview data could be designed to more fully identify classroom norms.

An additional limitation of this study surrounds the sample size: this study rests on detailed analyses of about twenty- to sixty-minutes of argumentative discourse for four classes. The small number of classes raises questions regarding the generalizability of these findings: Would other classes argue in different ways? What I believe to be the more vexing challenge related to the sample size of this study is that I was able to analyze only one argumentative discussion for each of three classes and two for the fourth. This raises questions regarding the conclusions one can draw relating the typical classroom discourse to the students' argumentative discourse. For example, if I had been able to observe Mr. S' students participate in another Whole Class Debate, would it have resulted in a critical dialogue (as did the one examined for this study), or would they have argued in a different way? Without conducting a within class comparison of students engaging in similar activities, all of my claims regarding the influence of typical class discussions on students' adaptations of argumentation are weakened.

Finally, I believe that this study was limited with respect to how it analyzed the typical classroom discourse. First, it ignores the potential impact of the students' larger communities. Cobb, Stephan, McClain, Gravemeijer (2001) had a similar limitation that they described by saying:

> its [this study's] treatment of social context is restricted to norms and practices that are established in the course of face-to-face classroom interactions. The approach, therefore, does not take account of the location of classrooms within schools and local communities, and ultimately within the activity system that constitutes schooling in the United States (p. 156).

Applying this to my study suggests that students in Mr. S' class argued by engaging in a critical dialogue not because this form of argumentation aligned with the epistemology of the typical interactions in that class (as I have argued), but because either 1) it was a discourse style that the students frequently used in other contexts or 2) the school's emphasis on improving test scores created a culture of competition to succeed. Similarly, it might be possible to explain some of the challenges Ms. B had with her 2006 students by examining the students' roles in the school more generally as well as their interactions outside of school.

While I acknowledge this weakness, I suggest that the typical interaction patterns are a proxy for the norms students were learning in other, larger, contexts. That is, these other contexts were influencing the interactions that I saw in the classroom everyday, whether or not argumentation was a focus. Thus, by comparing the typical class discussions with the way students took up the practice of argumentation, I am at least partially accounting for the norms of the students' larger communities—at least for those norms that carried over into their typical class discussions. What this study does not do is explain where these norms come from. For example, my study does not reveal whether the emphasis on competing to get right answers seen in Mr. S' class—across both argumentative and typical days—was fostered by the teacher, school climate, or aspects of the community in which the school resides, or the influence of an individual student.

The analyses of the typical classroom discourse were further limited by my definition of "typical." Recall that the typical discussions I analyzed all occurred within the context of the IQWST unit, which was designed to facilitate students' active participation in knowledge construction. Thus, it is possible that the discussions that I labeled as "typical" were in fact different from the ways in which the students and teachers in each class interacted throughout the school year. How much did the IQWST curriculum materials influence their typical discussions? However, comparing the typical class discussions that occurred in the first and second halves of a single class' enactment of the IQWST unit reveal no real differences. Thus, participation in the unit did not appear to change the discourse patterns over time. It is possible that the unit inspired drastically different interactions on the first day of the enactment and that these interactions continued throughout. However, given my findings regarding the challenges of taking up new discourse practices, this seems unlikely. Instead, I argue that the typical class discussions that occurred throughout the unit reflect the ways in which the students and teachers in each class interacted throughout the school year, regardless of whether they were enacting an IQWST lesson.

6.4.1 Future work

Some of these limitations are best addressed by future studies. I am particularly interested in examining the relationship between existing classroom norms, the framing of the argumentative discussion and the aspects of argumentation that students emphasize in that discussion. For example, can I find consistencies across multiple argumentative discussions that occur in a single classroom? Similarly, this dissertation suggests that two classes that adapt the practice of scientific argumentation in similar ways should have similar existing classroom practices. Examining this possibility is one way to both test the theories coming out of this dissertation and explore the mechanism through which the existing classroom practices influence students' adaptations of new practices.

In addition, this study did not examine the quality of the students' arguments: I do not assess the accuracy, the use of empirical evidence during their justifications, nor the depth of the arguments. The categorization of the class' arguments was the first step to understanding variation in the quality of students' arguments. For example, it allows one to examine whether engagement in a critical dialogue produces more complex arguments than participation in an information-seeking dialogue? Similarly, future studies could examine the relationship between the type of argument enacted and the accuracy of students' final understandings.

Finally, this study raises questions regarding learning progressions: students in three of the four classes in this study struggled with revising their claims in light of one another's arguments. Moreover, these struggles emerged out of the lack of alignment between this aspect of argumentative discourse and the beliefs and goals typically communicated in the classroom discourse. This suggests that fostering this aspect of argumentation requires time for the beliefs and goals implied by the class' discussion to shift. What would this process look like?

6.4 SUMMARY OF CONTRIBUTIONS

In Chapter 3, I introduced design strategies for helping to transform the way students typically interact with one another, the teacher and the content. These design strategies include: making the epistemic criteria explicit; creating a need for students to use evidence; and creating a need for students to attend to one another's ideas. In Chapter 5, I examined the utility of these strategies. It was difficult to find clear evidence that the implementation of the first strategy—the IQWST instructional framework—was tied to students' justifying their claims. But, given previous work with this framework, it is likely that it was. That said, the second and third strategies are clearly linked to the rate with which students justified their ideas. In addition, it appears that the final strategy can also facilitate student-to-student interactions.

In Chapter 4, I identified four different ways that students could make the practice of scientific argumentation meaningful in their classrooms. One variation, arguing to share information, revealed a class in which the argumentation mirrored typical classroom practices without demonstrating key aspects of argumentative discourse. The others types of arguments observed in this study introduce tradeoffs in that they each represent a form of argumentative discourse that prioritizes one aspect of the practice over another. For example, Ms. W's class was the only one in which revision of ideas was relatively common. However, these students provided little evidence that they were attending to one another's ideas. In contrast, Mr. S' students actively engaged with one another's ideas by evaluating and contradicting them. However, as demonstrated by the lack of revision in this class, these students rarely learned from this discussion. Across these enactments students exhibited a consistent struggle with balancing the goals of sensemaking and persuading.

Beyond highlighting a tension that under girds the goals of argumentative discourse, this analysis, this taxonomy of argument types, lays the ground work for future work in which we engage in more nuanced studies of students' engagement in scientific argumentation. No more will we be asking what happens if students argue or whether can we get students to argue. Instead, we should be asking: What happens when students participate in a particular argument type and can we foster that particular form of argumentative discourse?

In Chapter 5, I examined how the scaffolds provided by the immediate learning environment (including teacher strategies, curricular supports and activity structures) and the typical class discussions in each class combined to facilitate students' adaptations of the argumentative discourse. Among other findings, this portion of the study highlighted the importance of student autonomy for enabling student-to-student interactions.

Finally, in Chapter 6, I combined the above analyses in order to foreground the relationship between typical interaction patterns, the immediate learning environment and student adaptation of the practice of scientific argumentation. This work underscores the importance of taking the existing classroom practices seriously by demonstrating that students will interpret scaffolds and activity structures in terms of those existing classroom practices: The beliefs and goals that align with the ways in which students typically interact will influence how they make sense of the new practice. In this chapter, I proposed three design strategies that work together to address this challenge in order to facilitate classroom communities in taking up new practices, such as scientific argumentation.

In terms of other researching and understanding student engagement in other scientific practices, this study demonstrates a methodological approach to examining the relationship between existing classroom practices and classroom communities adaptations of new scientific practices. That is, this study has demonstrated that it is possible to understand student adoption and adaptation of a scientific practice—argumentation—in terms of the composite practice that is formed by combining the new practice and existing classroom practices. While research suggested that this relationship existed, this finding was not a foregone conclusion: it was possible that each of the classroom communities in which I worked would completely reject the argumentative practice (similar to Ms. B's 2006 class) rather than adapting it to fit within their existing class culture. In addition, it was possible that the students' argumentative discourse would reflect idiosyncrasies of student personalities or expectations that were not apparent in their typical class discussions. This, combined with the fact that each of the aspects of argumentative discourse was present in at least one of the class' argumentation, indicates that understanding student participation in inquiry practices requires that we understand the context in which the enactment occurred. That is, this dissertation demonstrates that evidence of students struggling with particular aspects of a new practice indicates a need to understand the relationship between that aspect of the practice and the students' classroom culture.

Thus, this dissertation is the first step in a larger research program that explores the relationship between existing classroom practices and student participation in the practices of scientific inquiry. It demonstrates the viability of research such as this and illustrates methodological steps for engaging in it. In particular, this dissertation suggests that researchers must identify the underlying aspects of inquiry practices rather than considering them as a single entity. In addition, this study demonstrates the utility of analyzing classroom discourse for the aspects of the new practice when the practice is and is not a focus of the activity—it demonstrates the utility of using existing classroom practices to understand their adaptations of new practices. It is through these analyses that we can begin to understand the roots of the challenges that face students while engaging in new scientific inquiry practices.

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APPENDIX A: SAMPLE INTERVIEW PROTOCOLS

Sample Pre-Interview

ATTITUDES ABOUT SCIENCE CLASS

1. Do you like science class? Why or why not?
2. Do you feel like you're good at science?
3. What are your favorite science topics? Least favorite?
4. What is your favorite thing about science class?
5. What is your least favorite thing?
6. Do you ever do science outside of school?

DISCOURSE NORMS

7. When there is a whole class discussion, what are you typically doing? Do you take notes? Do you talk? Do you listen to your classmates?
8. How important is it to get the right answer when the whole class is talking about something? What happens if someone has a different answer?
9. Do you ever explain your ideas about science to your classmates? Do your classmates ever explain their ideas to you? Can you give an example of when that happened?
10. Have you ever tried to convince your classmates of an idea in science that you had? Can you give me an example?

ACTIVITY NORMS

11. How often do you work with your classmates in small groups?
12. What kinds of activities do you do in small groups? <e.g., worksheets, labs, discussions, problem solving, projects>

13. Do you have a role or job when you work in small groups?

14. Does your class ever have presentations? Describe what happens. Do you enjoy them?

15. Do you ever comment on, give feedback or constructive criticism on your classmates' ideas?

Will present students with a dataset and 3 explanations that address a question that students answered over the course of their most recent unit. Explanations will have the following characteristics:

1. Be supported with inferences, but no evidence
2. Have 1 piece of evidence (insufficient evidence)
3. Have good evidence and inferences supporting it

16. Will ask students to evaluate the 3 explanations: which is most convincing to scientists?
17. What are looking for in the explanation that makes it more scientifically convincing than the others?
18. Why is explanation X (student selected) most convincing to scientists? Why did you not pick explanation X-1? What about X-2? (have student explain why the remaining 2 were unconvincing)

From here on, focus on the explanation the student selected.

19. Do you know the word evidence?
    a. If no: Define it: The evidence are the facts that support the conclusion. They help people figure out the answer to the question. Think about evidence in a crime scene.
    b. If yes: Are you looking for evidence when you decide which is the most convincing?
20. Is there any evidence in this explanation? [have them point it out].
    a. Is this evidence good or bad? Why?
21. Repeat for the other 2 explanations: point to the support and ask: is this evidence? is it good or bad evidence?

22. Look at your most convincing explanation. Do you think that if you gave that to someone else they could look at the information in it and come up with a different claim? Could they decide that Sarah could have a pet lion?

Sample Post-interview

General:

1. What kinds of things have you done in science class, in the last month?
2. Have you worked in small groups? What kinds of things did you talk about?
3. Can you tell me about a memorable discussion you had with the whole class? Why was that memorable?
4. Where there times in the last month when you had an idea or answer and you thought it was really important to convince your classmates (or group members) that you were right?
    i. If not, can you just talk about a time when the whole class (or your group) didn't agree and tried to reach agreement?

    b. How did you try to convince them? Were you successful? Did they change your mind?

Lesson 18

5. Why were you working on your case study mysteries?
6. Can you describe what you were doing in the groups at the end of the unit? (point to student sheet 18.3 if necessary)
    a. Why were you doing that?
    b. Why did you move from partners to the larger group?
7. Can you talk about the presentation you did?
    a. What did you present?
    b. Were you happy with what you presented? Why?

i. How did you know what you were doing was right? When did you decide you were ready to present?

c. Did you listen to your classmates? Did you learn anything?

d. What was the point of presenting? You worked in pairs and then in the larger group and then presented to the whole class, why did you go through all of those steps?

Post Test:

Read over their explanation of the Aleutian Islands.

8. Do you still believe this answer? Why?

9. How did you know when you had written enough?

   a. If necessary, why are each of these components (claim, evidence and reasoning) important?

10. While you were writing and deciding it was "good enough" who were you thinking about?

11. Present students with an alternvative explanation: "I read the article you looked at and tried to figure out if anything else could explain the decline in grass. Can you read my explanation and tell me if it convinces you? [see below] Do you think this explanation is right or wrong? Why?

    a. How would you improve it?

    b. How could you test between this explanation and yours?

Note: If student is convinced by alternative at the end of the interview, make sure they know that their answer is actually correct. There is no evidence in the article about temperature so it is purely hypothetical and their answer is stronger. The point of the question was to learn about how they compare answers, but we don't want them walking away thinking they did poorly on the test.

Alternative Explanation:

Why did the grass population decrease?

The temperature has been decreasing from the 1700's until now. This has allowed the artic foxes to survive on the Aleutian Islands. The lower temperatures are killing the grass. This makes sense because we know that biotic and abiotic factors affect organisms in an ecosystem.

APPENDIX B: OVERVIEW OF *2005 VERSION OF THE ECOSYSTEMS UNIT*

What will survive?

Part 1: How do we stop an invasion?

Part 1 consists of 8 lessons that are designed to help students answer the question: **How do we stop and invasion?** The material has been organized into four learning sets, each dealing with a different aspect of the question. The following provides an overview of each learning set.

LEARNING SET 1: WHAT IS AN INVASION? (3 DAYS)

Learning Set 1 begins by introducing the problem of invasive species and gets the students to define what is meant by a biological invasion. After developing an understanding of invasion and invasive species, students look at how a specific invasive species – the sea lamprey – moved from its native habitat to the new ones. Students are presented with a challenge of constructing a plan for "stopping an invasion" – for eradicating the sea lamprey.

LEARNING SET 2: WHAT LIFE STRATEGIES ALLOW AN ORGANISM TO SURVIVE IN ITS ENVIRONMENT? (6 DAYS)

In Learning Set 2 students develop their understanding of how the sea lamprey's characteristics help it to survive in a non-native ecosystem. They study the functions that an organism's structures serve to allow it to survive. They then dissect the sea lamprey in order to explore its structures. In the first lesson of this learning set, students are introduced to the scientific explanation framework and they work as a class to evaluate sample explanations. In the subsequent lesson, students construct their own scientific explanations individually.

<u>LEARNING SET 3:</u> HOW ARE ORGANISMS IN AN ECOSYSTEM CONNECTED AND WHY IS THIS IMPORTANT? (6 DAYS)

In Learning Set 3 students learn about the relationships between organisms within an ecosystem and the various ways these organisms are able to survive, by looking specifically at their feeding and reproductive strategies. After gaining familiarity with food webs, students explore a computer simulation of an ecosystem. At the conclusion of this lesson (lesson 6), they work in pairs to construct and defend a scientific explanation. This is the first explanation analyzed in this study.

<u>LEARNING SET 4:</u> HOW HAVE SEA LAMPREYS AFFECTED THE GREAT LAKES ECOSYSTEM AND CAN WE FIND A SOLUTION? (3 DAYS)

In Learning Set 4 students return to the idea of invasion and look at the implications of the addition of the sea lamprey to the Great Lakes ecosystem. They are then asked to propose a solution based on what they have learned about an organisms survival needs. This solution is presented in the form of a scientific explanation and is the second explanation included in this study.

Part 2: Natural Selection—How do populations change over time?

Part 2 consists of five lessons addressing the question of how populations survive and change over time. This question is addressed in two parts. First students look at the variation found within the same species. They then examine how natural selection. Students spend most of Part 2 in a computer environment called The Galapagos Finches in which they will explore real data in order to determine how some finches survived a catastrophic event.

LEARNING SET 1: HOW DO INDIVIDUALS WITHIN A SPECIES DIFFER AND HOW DO THESE VARIATIONS AFFECT SURVIVAL AND REPRODUCTION? (3 DAYS)

In Learning Set 1, students are introduced to the concept of "environmental stress". They then look at how traits and variation provide an advantage to some individuals within a population and a disadvantage to others. In each of the two lessons contained in this Learning Set, students construct a scientific explanation that is not discussed in this study.

LEARNING SET 2: WHAT IS NATURAL SELECTION? (15 DAYS)

In Learning Set 2, students first explore and construct scientific explanations regarding how an environmental stress can affect the variations within a population. Students then move to the Finch software and spend the majority of the Learning Set investigating the question "Why did some finches die and others survive?" The culminating activity for this half of the unit is the students' constructing and defending scientific explanations that solve this mystery. This is the third scientific explanation examined in this study.

APPENDIX C: OVERVIEW OF *2006 VERSION OF THE ECOSYSTEMS UNIT*

"Where have all the creatures gone?"

"Where have all the creatures gone?" is the title of the IQWST 6th grade biology unit. This ecosystem unit focuses on organisms' needs for survival and what happens when those needs are not met. It is organized around the driving question: "What can cause populations to change?" This question is addressed through the investigation of a specific population change: students examine why the trout population in the Great Lakes decreased significantly from 1930 to 1990. Over the course of this investigation, students learn why food is important, what structures different organisms have in order to eat and reproduce, what the different relationships are between organisms (e.g., predator/prey, producer/consumer and competition) and what abiotic factors affect ecosystems. All of these pieces combine to help students construct an evidence-based scientific explanation about why the trout population has decreased so drastically.

Beyond the content learning goals, this unit is designed to introduce and motivate the practice of constructing and defending scientific explanations. Over the course of the unit the students construct four different explanations, using the evidence they gather and the scientific principles they learn to defend a claim regarding one of their investigation questions. For example, in Lesson #8 students use graphs of population fluctuations to determine what an unknown organism eats. They then construct scientific explanations, using evidence from the graphs and principles about the relationships between organisms, to defend their claims.

LEARNING SET 1: INTRODUCING THE DRIVING QUESTION

In Learning Set 1, students are introduced to the general driving question and the specific mystery they will investigate. Lesson 1 introduces "biology" as the study of living things and provides students with an opportunity to go outside and observe living things for themselves. Students use their observations and pictures of living things in other areas to raise initial questions about what could cause a population to change. This brainstorming activity is organized into a Driving Question Board (DQB), that helps drive the students' investigation.

In the second lesson, students are introduced to the specific population they will be investigating: the trout, in the Great Lakes. They examine graphs of how this population has changed over time and read about the effect that decreasing trout has had on fisherman, in the region. At the conclusion of this learning set students are ready to begin investigating their mystery.

LEARNING SET 2: WHAT IS FOOD FOR LIVING THINGS?

Learning Set 2 begins with students narrowing in on the food part of the class DQB: if starvation caused the trout population to decrease, do we know why? Why is food so important? In this Learning Set, students learn that food provides living things with building materials and the energy necessary to grow and do things. This Learning Set touches on photosynthesis when students realize that everything they eat is connected to plants and that plants do not eat, so they must make their own food. Photosynthesis will be covered in the 8^{th} grade Chemistry unit, so this Learning Set does not go into detail about the process itself.

This Learning Set also introduces the "scientific principles." Scientific principles are statements of general science knowledge with which the students agree. In this unit, the principles are recorded on a class list. Principles are not recorded unless all of the students agree that the new idea is correct. In this Learning Set they record scientific principles about what food is and why it is important.

Students use these principles to defend their claims in scientific explanations. With the teacher modeling and scaffolding the process, students construct one explanation and evaluate another, in this Learning Set. In the first, students construct a scientific explanation that defends the claim "water is not food." Constructing this explanation helps confront a common student conception that living things get energy from water. Students then help the teacher choose the most convincing scientific explanation to defend the claim "plants need food." Choosing between explanations allows students to evaluate why some explanations are more convincing than others, thereby helping to solidify the components of a scientific explanation (see the Scientific Explanation front matter).

LEARNING SET 3: HOW DO LIVING THINGS GET FOOD FROM OTHER ORGANISMS?

In Learning Set 3, students return to the trout mystery and DQB using what they just learned about food to help determine what is happening to the trout. This Learning Set begins with an introduction to food webs as students consider the possibility that maybe the trout isn't getting enough food or maybe something is eating the trout. Students construct a preliminary definition of the word "ecosystem" in this lesson that will be refined in Lesson #11.

In Lesson #6, students are introduced to the sea lamprey, an invasive species that eats the trout. Students examine graphs of the sea lamprey population and consider the possibility that the sea lamprey is causing the trout's population problems.

This learning set concludes with students investigating what makes the sea lamprey a successful predator. While dissecting the sea lamprey, students learn that the structures of the sea lamprey make it very good at attacking trout. This introduces students to the scientific principle that organisms have different structures that help them perform functions such as eating and reproducing.

LEARNING SET 4: HOW DO ORGANISMS COMPETE?

In Learning Set 4, students investigate the ways in which organisms affect one another. In Lesson #9, they work with a computer model of an ecosystem containing foxes, rabbits and grass. They examine how the percent of grass in this ecosystem affects the rabbit and fox populations and construct a scientific principle about competition for resources. Students then examine the effects of an unknown invader on their computer ecosystem, observing population fluctuations to determine what the invading organism eats. This lesson concludes with students using the scientific explanation instructional framework to guide a debate in which the class attempts to reach consensus regarding the invader's food source. This debate serves to help motivate the practice of scientific explanations: Trying to convince one another of a claim helps students experience the importance of each of the elements of the explanation framework. For example, they realize that an explanation without evidence is not convincing.

In Lesson #10, students use their new understandings about how organisms can affect one another and how to read population graphs in order to analyze the trout mystery further. After examining their graphs they realize that the trout's food source is increasing, not decreasing so the trout must not be starving. Students then realize that while the sea lamprey appears to affect the trout, it is not the whole story. The trout population started to decrease before the sea lamprey entered the great lakes. Learning Set 4 concludes with students recording these ideas on the DQB and wondering what else could be affecting the troutEARNING SET 5: DO ABIOTIC FACTORS AFFECT POPULATIONS?

Learning Set 5 introduces abiotic factors. After exploring a range of abiotic factors and how they can affect organisms, the students identify a scientific principle regarding the effect of abiotic factors in ecosystems. This helps students finalize the definition of "ecosystem" as containing both biotic and abiotic factors. The students then focus on dioxin, an abiotic factor affecting the trout. Students examine graphs of dioxin and realize that it has been at unacceptable levels since the trout population started to decline. This is recorded on the DQB and is the final piece of the puzzle for students.

At the conclusion of Learning Set 5 students work together, reviewing the data they recorded on the DQB along with their scientific principles to construct scientific explanations about what affected the trout population. Given the data they collected there are three plausible and acceptable claims: 1) the sea lamprey affected the trout, 2) the dioxin is why the trout population decreased and 3) both the sea lamprey and dioxin affected the trout. The third claim is the most accurate, but each of these claims is acceptable and defensible given what students learned. This unit concludes with students debating their different interpretations of the data and recognizing the complexity that exists in ecosystems: each of the factors affects each of the populations.

Leema Kuhn Berland Vita

Education

Northwestern University, 2002 - present Evanston, Illinois
Doctoral Candidate, Learning Sciences
Advisor: Brian Reiser

Center for Curriculum Materials in Science, 2003 - present
Doctoral Fellow

Carleton College, 1995 - 1999 Northfield, Minnesota
Graduated Magna Cum Laude: 1999
Bachelor of Arts: Computer Science
Concentration: Educational Studies

RESEARCH EXPERIENCE

IQWST, Northwestern University, 2003 – present
Principal Investigator: Brian Reiser *Evanston, Illinois*

Project Description:

Investigate and Questioning our World through Science and Technology is an NSF-funded instructional materials development project focused on using research-based design principles to create middle school science units that meet national standards. (http://www.hi-ce.org/IQWST/Home.htm)

Research Assistant:

- Co-led an effort to develop a model for supporting scientific argumentation and explanation and a learning progression that became the basis of the IQWST effort to support scientific practices across multiple years and domains. Presented this learning progression to funders from NSF.
- Worked as a lead-designer revising pilot materials and designing an eight-week unit on ecosystems.
- Conducted empirical studies of unit enactments. Analyzed this data to drive unit revisions and to develop a theoretical model of argumentation in middle school science.

Lighthouse, Northwestern University, 2002 – 2003 Evanston, Illinois
Principal Investigator: Alfred Hess

PROJECT DESCRIPTION:

Conducted a study examining teachers that were historically successful helping minority students develop reading skills. Used this analysis to identify teaching practices and beliefs that other teachers could work towards.

RESEARCH ASSISTANT:

Collaborated with research team to design an observation schedule. Conduct classroom observations, assess inter-rater reliability and develop findings.

RESEARCH INTERESTS

Scientific explanation and argumentation
Inquiry based science
Nature of science
Fostering student driven, scientific inquiry

Design of learning environments
Collaborative learning tools

AWARDS/FELLOWSHIPS

Doctoral Fellow
Center for Curriculum Materials in Science — *2003–present*

Fellowship to participate in Doctoral Consortium
International Conference of the Learning Sciences — *July, 2006*

Fellowship to attend NSF K-12 Math, Science and Technology Curriculum Developers Conference
National Science Foundation — *February, 2006*

Best Paper Award
National Association for Research in Science Teaching — *April, 2005*

ARTICLES AND PUBLISHED CONFERENCE PRESENTATIONS

Kuhn, L. & Reiser, B. J. (in press). *Making sense of argumentation and explanation*. Journal of Science Education. Science Education

Kuhn, L., Kenyon, L., O., & Reiser, B. J. (July, 2006). *Fostering scientific argumentation by creating a need for students to attend to each other's claims and evidence*. In S. Barab, K. Hay & D. Hickey (Eds.), *Proceedings of the seventh international conference of the learning sciences* (pp 370-375). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Kenyon, L. 0., Kuhn, L, & Reiser, B. J. (July, 2006). *Using students' epistemologies of science to guide the practice of argumentation*. In S. Barab, K. Hay & D. Hickey (Eds.), *Proceedings of the seventh international conference of the learning sciences* (pp 321-327). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

CONFERENCE PRESENTATIONS

Kuhn L. (April, 2008). *Students' use of evidence in argumentative discourse*. Poster presented at the annual meeting of the National Association for Research in Science Teaching, Balitmore, MD.

Kuhn L., & Reiser, B.J. (April, 2007). *Bridging classroom practices: Traditional and argumentative discourse*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

McNeill, K. L. & Kuhn, L. (April, 2006). *Sequencing and supporting complex scientific inquiry practices in instructional materials for middle school students: Explanation and argumentation.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Kuhn, L., & Reiser, B. J. (April, 2006). *Structuring Activities to Foster Argumentative Discourse.* Paper presented at the American Educational Research Association, San Francisco, CA.

Kuhn, L. & Reiser, B. J. (April, 2005). *Students Constructing and Defending Evidence-Based Scientific Explanations.* Paper presented at the National Association of Research in Science Teaching, Dallas, TX.

INVITED PRESENTATIONS

Reiser, B.J., Kuhn, L., McNeill, K., Schwarz, C., Shwartz, Y. (July 2007). *What does it mean to support scientific practices in K-12 classrooms?* Plenary Session at the CCMS Knowledge Sharing Institute, Washington, D.C.

Kuhn, L., McNeill, K. L., Krajcik, J. & Reiser, B. J. (February, 2006). *Learning progressions for scaffolding student participation in scientific explanation and argumentation.* Presented at the NSF K-12 Math, Science, and Technology Curriculum Developers Conference, Washington, D.C.

Reiser, B. J., Kenyon, L. O., & Kuhn, L. (July, 2005). *Nature of Science in Action -- what should it look like when students use the nature of science understandings in classroom practice?.* Session at the CCMS Knowledge Sharing Institute, Lansing, MI.

Kuhn, L. & Reiser, B. J. (July, 2004). *Evidence-based scientific explanations: Student and designer understandings.* Poster presented at the CCMS Knowledge Sharing Institute, Evanston, IL.

McNeill, K. L., Kenyon, L., Kuhn, L. (July, 2004). *Student Explanations.* Session at the CCMS Knowledge Sharing Institute, Evanston, IL.

CURRICULUM MATERIALS

Finn, L-E., Kuhn, L., Whitcomb, J. L., Bruozas, M., & Reiser, B.J. (2006). Where have all the creatures gone? In Krajcik & B. J. Reiser (Eds.), IQWST: Investigating and questioning our world through science and technology. Evanston, IL: Northwestern University.

Bruozas, M., Finn, L.-E., Tzou, C., Hug, B., Kuhn, L., & Reiser, B. J. (2004). Struggle in natural environments: What will survive? In J. Krajcik & B. J. Reiser (Eds.), IQWST: Investigating and questioning our world through science and technology. Evanston, IL: Northwestern University.