Making Sense of Argumentation and Explanation

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ABSTRACT: Constructing scientific explanations and participating in argumentative discourse are seen as essential practices of scientific inquiry (e.g., R. Driver, P. Newton, & J. Osborne, 2000). In this paper, we identify three goals of engaging in these related scientific practices: (1) sensemaking, (2) articulating, and (3) persuading. We propose using these goals to understand student engagement with these practices, and to design instructional interventions to support students. Thus, we use this framework as a lens to investigate the question: What successes and challenges do students face as they engage in the scientific practices of explanation and argumentation? We study this in the context of a curriculum that provides students and teachers with an instructional framework for constructing and defending scientific explanations. Through this analysis, we find that students consistently use evidence to make sense of phenomenon and articulate those understandings but they do not consistently attend to the third goal of persuading others of their understandings. Examining the third goal more closely reveals that persuading others of an understanding requires social interactions that are often inhibited by traditional classroom interactions. Thus, we conclude by proposing design strategies for addressing the social challenges inherent in the related scientific practices of explanation and argumentation. © 2008 Wiley Periodicals, Inc. *Sci Ed* **93:**26–55, 2009

INTRODUCTION

In the last few decades, there has been increasing interest in students learning science through participation in scientific inquiry practices (American Association for the

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Advancement of Science, 1990; Collins, Brown, & Newman, 1989; Lave, 2004; Lehrer & Schauble, 2006; National Research Council, 1996; Warren & Rosebery, 1996). Within this broad goal, we see two emphases emerging: (1) Students should use data and scientific concepts to construct models or explanations about the phenomenon under study (Linn, Songer, & Eylon, 1996; Smith, 1991; Strike & Posner, 1985), and (2) students should engage in the scientific discourse of proposing and arguing about ideas (Blumenfeld et al., 1991; Driver, Newton, & Osborne, 2000; Duschl, 1990, 2000). Attempts to support inquiry-based approaches to science in classrooms have demonstrated that goals such as these are often difficult to achieve. Furthermore, neither the practices of scientists nor the desired practices for students are easily defined. That is, fostering student participation scientific practices, such as argumentation and explanation, requires that we identify those aspects of the practices that we, as educators and researchers, hold to be important for students (Krajcik, McNeill, & Reiser, 2008). Thus, in this paper, we propose a definition of these practices that rests on the instructional goals embedded in the practices. We examine the utility of this framework by using it to explain the challenges that learners experience when engaging in the related practices of explanation and argumentation. We begin by briefly reviewing the ways in which the two practices of explanation and argumentation are discussed in the field of science education.

Literature in both the philosophy of science and psychology suggests that no single definition of explanation can account for the range of information that can satisfy a request for an "explanation." For example, Nagel suggests that there are four different types of answers that be called "explanatory": deductive, probabilistic, teleological, and genetic (1979). However, within this broad category, many "explanations" can be seen as attempts to provide an account that specifies what happened and/or why it occurred (e.g., Brewer, Chinn, & Samarapungavan, 1998; Giere, 1988; Nagel, 1979). This general sense that an explanation is a causal account is found in the National Research Council's expectation that students construct explanations that provide "causes for effects and establishing relationships based on evidence and logical argument" (1996, p. 145).

If the goal of science education is to foster student participation in scientific practices then our understanding of explanation must expand to include the process of constructing these explanations. 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). If we want students to engage in the practices of knowledge construction, then we must understand how explanations are constructed and the social context that makes this practice meaningful. Science education literature addresses these questions by highlighting the social nature of developing explanations (e.g., Engle & Conant, 2002; Lehrer & Schauble, 2006; Scardamalia & Bereiter, 1994). For example, Ford and Forman (2006) describe learning in communities of both scientists and students as a process of constructing, testing, and revising understandings through public debates about how to best explain the phenomena under study. This view of science and science learning posits that explanations and models of scientific phenomena are constructed through social discourse in which these artifacts—these explanations and models—are questioned, evaluated, and revised. In other words, in scientific communities, explanations are developed through argumentation.

The everyday sense of argumentation typically suggests a competitive interaction in which participants present claims, defend their own claims, and rebut the claims of their opponents until one participant (or side) "wins" and the other "loses." Science educators (e.g., Driver et al., 2000; Duschl, 2000) and philosophers of science (e.g., T. S. Kuhn, 1962; Latour, 1980; Toulmin, 1972) extend this everyday understanding of argumentation to view it as “a form of collaborative discussion in which both parties are working together to resolve an issue. . . ” (Andriessen, 2007, p. 443). From this perspective, the work of resolving an “issue” or disagreement is the way in which individuals collaboratively construct explanations: Individuals compare conflicting explanations with the support for those explanations and work to identify/construct an explanation that best fits the available evidence and logic. As stated by Sandoval and Millwood (2005, p. 24) “Explanations are a central artifact of science, and their construction and evaluation entail core scientific practices of argumentation.”

In other words, the practices of explanation and argumentation are complementary. First, explanations of scientific phenomena can provide a product around which the argumentation can occur, as proponents of an explanation attempt to persuade their peers of their understandings. Second, argumentation creates a context in which robust explanations—those with which the community (the students) can agree—are valued.

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 explanation is a by-product 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). In other words, this second strategy uses the structure of a scientific argument—claims defended with evidence—to support students’ explanation construction. It is important to note that while we 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.

Other researchers have treated explanation and argumentation not as separate categories but as a single practice. For example, Hogan, Nastasi, and Pressley (1999) examine student reasoning as it is apparent in their explanatory and argumentative discourse, without differentiating or defining these modes of communication. Similarly, Bielaczyc and Blake (2006) show students’ use of argumentation when building explanations, while neither differentiating nor naming these practices. Instead, building off of 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 often-implicit combination of argumentation and explanation and the overlap in their pedagogical goals suggests that it is often sensible to combine them into a single practice. Throughout this paper, we refer to this practice as *constructing and defending scientific explanations*.

While this combination makes sense in terms of the related goals and processes of these practices, it results in a 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 these practices to better understand and support students in engaging in both explanation and argumentation. For example, students may find the argumentative goal of defending an explanation against critique more challenging than 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?

Thus, we begin this paper by identifying the underlying instructional goals of constructing and defending explanations. We contend that understanding the implicit goals inherent in the practice of constructing and defending scientific explanations allows us to analyze the challenges that students face when engaging in these practices; this in turn will help designers create contexts that motivate and support students to engage in this practice. We test the utility of these goals as a tool for curriculum designers and researchers by using them to understand both various strategies for fostering this complex practice and the challenges that students face when engaging in the construction and defense of scientific explanations.

Three Goals of Constructing and Defending Scientific Explanations

Drawing on relevant design research, analyses, and theory, we identified three distinct goals for constructing and defending scientific explanations: (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. We contend that each of these goals is a crucial step for engaging in knowledge building via the social process of evaluating and defending claims. Thus, we propose the goals of *sensemaking*, *articulating*, and *persuading* as a framework for understanding student participation in the practice of constructing and defending explanations. In the following section, we define each of these goals and highlight the instructional value of each one.

The first goal of these practices 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 et al., 2000; Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl, 2000). For example, sensemaking occurs when students interpret population graphs 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).

The second goal of constructing and defending explanations is to *articulate* one's understandings about what or why an event occurred. As stated by Sawyer: "Articulating and learning go hand in hand, in a mutually reinforcing feedback loop" (2007, p. 12). Other science education researchers agree with this focus on communication as part of learning; the basic tenant 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, Lund, & Michael, 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 scientific explanations is one step in the process of developing shared understandings of the phenomenon under study.

The third goal of constructing and defending explanations, *persuasion*, emphasizes the complexity of knowledge building by describing it as social process of considering and reconciling competing ideas from multiple individuals 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. S. 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 debate differing proposals 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 on one another. However, they are not equivalent: One can imagine a student 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. 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 constructing and defending scientific explanations 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, we do not see sensemaking, articulating, and persuading as steps in a process. Instead the relationship between these goals is a fluid one: not only do individuals iterate between these goals while constructing and defending scientific explanations, 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, to determine whether 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.

We see the complex and overlapping practices of explanation and argumentation as requiring engagement in each of the three goals of sensemaking, articulating, and persuading. Moreover, this aligns with the vision of learning science through participation in practices that was highlighted in 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 argument 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, Schweingruber, & Shouse, 2007, p. 40)

Thus, participation in the practices of scientific communities requires learning the skills of sensemaking (i.e., constructing arguments), articulation (presenting arguments), and persuasion (debating arguments).

We suggest that viewing student work in terms of these three instructional goals can clarify students' successes and challenges in constructing and defending scientific explanations and consequently inform the design of supports for this practice. These goals can provide a framework for differentiating between those students who emphasize these goals differently: for example, between those who are eager to *persuade* others of their understandings but do so by relying on plausibility and logic rather than using the evidence to *make sense* of the phenomenon, and those who are more likely to carefully construct and *articulate* explanations but fail to communicate them in a *persuasive* way. Furthermore, we suggest that each aspect of the practice may require different types of support for students. For example, using evidence when *making sense* of phenomena may be a key conceptual challenge, while engaging in the *persuasive* discourse of argumentation may involve shifts in how students and teachers interact.

This paper proposes these three goals as a framework for understanding student engagement in constructing and defending scientific explanations. We explore the utility of this framework in two ways. First, we briefly use the goals of sensemaking, articulating, and persuading to understand two common strategies for facilitating student engagement in explanation and argumentation. In this discussion, we explore which of the three goals these particular scaffolding strategies address and how they do so. Second, we investigate student work in these practices, using these three goals to characterize the challenges that students face and successes students have when engaging in the practice of constructing and defending scientific explanations.

USING THE FRAMEWORK TO UNDERSTAND CURRICULUM DESIGN

In this section, we use the goals of sensemaking, articulating, and persuading to compare two strategies for supporting students' construction and defense of scientific explanations. The first can be characterized as supporting the goal of *persuasion* to motivate sensemaking while the second explicitly supported students' *articulations* to guide their sensemaking processes.

The first design strategy we examine begins with the understanding that typical classroom interactions can limit students' opportunities to *persuade* one another of their ideas. For example, the most common activity structure initiate–respond–evaluate (IRE) (Mehan, 1979) can be antithetical to students interacting with one another's ideas (Lemke, 1990). IRE occurs when the teacher asks a question, a student answers, and the teacher responds (evaluates) to the answer given. This interaction style creates little opportunity for students to respond to one another meaning they have few chances to state whether they are persuaded by one another's arguments. Moreover, even when students respond to one another's ideas in these classrooms, IRE can limit their engagement with persuading one another because they have little authority: "What would be the point in trying to convince your classmates that your ideas has merit if the teacher would step in and solve the controversy with a simple yes or no?" (Cornelius & Herrenkohl, 2004, p. 485).

A common approach to facilitating students' construction and defense of scientific explanations tackles this challenge by explicitly creating supporting the goal of *persuasion*. For example, Hatano and Inagaki (1991) asked students to investigate phenomena with multiple plausible explanations, select and defend the explanation they believe to be most accurate, and use evidence to reconcile the differing explanations. Osborne et al. (2004) used a variety of strategies to facilitate students constructing and defending scientific explanations but "a common framework for most of the materials [they] have developed [took] the form of presenting or generating competing theories for students to examine, discuss, and evaluate" (p. 1001). Both of these approaches created opportunities for students to engage in persuasion by highlighting their different understandings. They then used these differences to motivate sensemaking. That is, these approaches scaffolded student sensemaking by highlighting the students' differing understandings and enabling them to make sense of these differences through *persuasive* discourse.

An alternative instructional strategy is to support students' sensemaking process by explicitly structuring the ways in which students *articulate* their explanations. This approach draws on Toulmin's (1958) description of an argument as being a claim that has been justified and attempts to address findings that students have difficulty differentiating between their inferences (i.e., explanations, models, or predictions) and supports for those inferences (D. Kuhn, 1989; D. Kuhn, Black, Keselman, & Kaplan, 2000; Zeidler, 1997). Specifically, many designers support students' sensemaking by guiding them to *articulate* explanations that can be defended by evidence. For example, Belvedere, a learning environment created and investigated by Suthers et al. (1997), is designed to support students in distinguishing between evidence, prior knowledge, theories, and the connections between them. Belvedere does this by making these types of knowledge explicit in the computer representations of the students' explanations. When working in this environment, students record and connect the evidence they collect with the hypotheses they generate. Sandoval and Reiser (2004) also designed software to help students differentiate and relate their explanations and evidence. That is, similar to Belvedere, this learning environment structured the students' *articulation* to influence their *sensemaking* process.

The design approaches presented by Sandoval and Reiser (2004) and Suthers et al. (1997) differ in the structures that they emphasized and the ways in which they highlighted these structures. However, they are all based on the assumption that highlighting the structural elements necessary in the *articulation* of an understanding, such as evidence, will help students to recognize the importance of various types of knowledge for *sensemaking*. This type of scaffolding supports students' *sensemaking* by providing tools that students can use to communicate their explanations in a way that is consistent with the norms of the scientific community.

Using the goals of constructing and defending scientific explanations to interpret these two general design strategies helps to characterize the differences between them. In the first, we see the designers attempting to motivate students to make sense of the phenomenon under study by creating situations that draw attention to their differing understandings. In other words, this strategy explicitly enables student engagement in the goal of *persuasion* to facilitate student sensemaking. On the other hand, designers in the second strategy we examined focus on challenges students have with articulating the evidence for their explanations. This approach attempts to guide student sensemaking by structuring the ways in which students *articulate* their understandings.

The above discussion illustrates how the goals of sensemaking, articulating, and persuading can be a useful tool for characterizing how learning environments support students in constructing and defending scientific explanations. In the following sections, we explore the utility of these goals for understanding strengths and weaknesses students have when engaging in this complex practice.

USING THE THREE GOALS TO UNDERSTAND STUDENTS' WORK IN THE PRACTICE

We examine students' strengths and weaknesses around the practice of constructing and defending scientific explanations in the context of a learning environment that was explicitly designed to facilitate this practice because this practice rarely occurs in classrooms, when it is not an explicit focus of the instruction (Lemke, 1990; Mehan, 1979; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Thus, choosing a learning environment designed to facilitate students in constructing and defending scientific explanations was necessary if we were going to examine student engagement in this practice. The learning environment we use comes from the Investigating and Questioning our World Through Science and Technology (IQWST) research and design initiative in which we create, enact, and research middle school science curricula designed to use project-based investigations as a context for student participation in scientific practices (such as constructing and defending explanations). The IQWST team began by creating and researching two 6-week middle school units—the chemistry unit *How can I make new stuff from old stuff?* (McNeill et al., 2004) and the biology unit *What Will Survive?* (Bruozas et al., 2004).

This study uses enactments of the IQWST biology unit, *What will survive?*, to examine students' successes and challenges with constructing and defending scientific explanations. While our analysis may elucidate goals with which the IQWST framework had more and less success, the goal of this paper is not to test the instructional approach utilized in the IQWST curriculum. Instead, based on prior studies, we assume that the IQWST curriculum successfully supports students in constructing and defending scientific explanations (McNeill et al., 2006) and use it as a context for both examining the strengths and the weaknesses students have when grappling with this practice when it is supported, and testing the utility of the three goals for identifying those strengths and weaknesses.

Learning Environment

McNeill, Krajcik, and colleagues (McNeill & Krajcik, 2007; McNeill et al., 2006; Moje et al., 2004) have developed an instructional framework for supporting explanations that has been used in IQWST curriculum materials. This framework uses the second instructional strategy discussed above to support this practice: It structures how students articulate their understandings to guide their sensemaking. To that end, the IQWST instructional framework for constructing and defending scientific explanations builds on Toulmin's argumentation model and similar design endeavors (e.g., Clark & Sampson, 2007; Erduran, Simon, & Osborne, 2004; Sandoval & Reiser, 2004; Suthers et al., 1997) to make explicit the importance of making claims that can be justified with evidence and scientific ideas. This framework, as presented by McNeill and Krajcik (2007), contains three components:

1. *Claim*: the answer to the question
2. *Evidence*: information or data that support the claim
3. *Reasoning*: a justification that shows why the data count as evidence to support the claim.

The IQWST units introduce and define these components by supporting whole class discussions about them and providing scaffolds in the written materials. In the following sections, we provide general definitions and rationale for each component of this IQWST claim/evidence/reasoning framework.

Claim. The *claim* is an answer to the question. In the early investigations of this framework, it became clear that the claim is the easiest component for students to construct in their own writing and to identify in the writing of others (McNeill et al., 2006). Depending on the question asked, the claim could be a description of what happened or an identification of the critical causal factor. For example, in Lesson 7 of the *What Will Survive* unit, students are asked to explain what happened to a native fish population when the sea lamprey was introduced. In contrast, in Lesson 13, students are asked to identify the critical characteristic that enabled some finches to survive a drought. Regardless of the type of information expressed in the claim, it is the piece of information in the scientific explanation that the other two components—the evidence and reasoning—will defend.

Evidence. As stated by Driver et al. (2000), "Scientists hold a central core commitment to evidence as the ultimate arbiter between competing theories" (p. 297). The IQWST instructional framework defines the evidence component as the scientific data that students gather and combine to construct and defend their claims. In this curriculum, evidence could take a number of forms including traditional numerical data (e.g., changes in population sizes), observations (e.g., sea lamprey have millions of eggs, as seen in a dissection), and facts that were revealed in readings and discussions (e.g., the sea lamprey eats the trout).

Reasoning. A key challenge to designers of inquiry curricula is to create supports that promote reflection instead of simply "doing" the activity (Barron et al., 1998; Jimenez-Aleixandre et al., 2000). Furthermore, early uses of the IQWST instructional framework revealed that students would provide claims and state evidence but not articulate why the evidence was important or relevant (McNeill & Krajcik, 2007; McNeill et al., 2006). The "reasoning" component was designed to address these challenges by highlighting that students must connect their claims and evidence. There exist two ways students could fulfill this aspect of the instructional framework: (1) include relevant background knowledge or scientific theories and (2) describe the logical connections between the evidence and their claim.

Clearly the logical connections between evidence and claims could be inferences—an assertion used in reasoning could be "new" information that itself has to be defended. Thus, the categorization of an inference as either claim or reasoning depends on whether it is being treated as a new claim or as support: if the proposed scientific explanation indicates that the logical connections are debatable and require additional support, than they would be considered additional claims; however, if the connections were used to defend a claim then they would be considered reasoning. Moreover, if an inference that was used as support for a claim is questioned by others, then it could become a claim in future scientific explanations that respond to that question. For example, in explanations of population fluctuations in a Galapagos ecosystem (Reiser et al., 2001; Tabak & Reiser, 2008, in press), students attempting to explain why finches died in a particular year made the claim that the birds died of starvation, and supported that claim by reasoning that a drought led to the death of most plants on the island, so the birds had no seeds to eat. If another student were to question the assertion that a drought led the plant population to decrease, this assertion—that was first part students' reasoning—would become the claim of an additional explanation in which the students combined graphs of the plant population and rainfall decreasing simultaneously. This emphasis on the function an assertion plays in a scientific explanation rather than an independent assessment of whether the assertion is inferential or factual is important, because it indicates the fluidity of these three aspects: A single assertion could fulfill multiple roles, depending on its use.

The components of claim, evidence, and reasoning, as described by McNeill and Krajcik (2007), are dependent on one another. For example, refining the reasoning could require a student to reevaluate their claims. Moreover, after the construction of the claim and the statement of the supporting evidence, students might need to reinterpret the general science concepts under study, to more closely align with their evidence and claims. That is, students may need to refine their reasoning after they have identified their claim and evidence. In fact, research suggests that students' successful work within this framework is associated with increased content learning (McNeill & Krajcik, 2007; McNeill et al., 2006). Thus, this instructional framework is designed to do more than impose a structure on the students' product; by requiring that students ensure that each component is included and connected to the others, this framework is designed to support the students' sensemaking process.

In terms of the three goals of constructing and defending scientific explanations, the IQWST framework is designed to highlight the necessity that students consider the specific evidence and the general science concepts under study when making sense of their experiences. In addition, the framework provides a structure for the product that helps students articulate their explanations and makes explicit the types of information that one must use when persuading others of a claim. Thus, similar to the second design approach discussed above, the IQWST instructional framework structures how students articulate their explanations to influence their sensemaking processes.

Scientific Explanations in *What Will Survive*

In this paper, we focus on enactments of the IQWST biology unit *What Will Survive?* This is an 8-week unit that is broken into two parts. In Part 1, the students construct proposals, in the form of a scientific explanation, for removing an invasive species (the sea lamprey) from the Great Lakes. To construct this plan, students investigate the concepts around the interconnectivity of food webs, competition, and the relationship between structure and function (e.g., the effect of the shape of the bird's beak on food choice and, thus, habitat). In Part 2, students examine the causes of population fluctuations, focusing on the selective survival of some finches during a catastrophic drought. During this half of the unit, students examine natural variation and differential survival. The appendix provides an overview of this unit.

The *What Will Survive* unit supports the practice of constructing and defending explanations by introducing the practice, defining the three components found in the instructional framework, and providing students and teachers with eight opportunities to construct and defend explanations. This study focuses on three of those opportunities. These three questions represent the types of questions that the students were asked and the evidence that the students had access to throughout the unit. The diversity of scientific reasoning required by these different questions creates opportunities for students to engage in the practice of constructing and defending scientific explanations in a variety of ways. Thus, by selecting these questions, which included a wide range of data and questions, we hoped to test the utility of the three goals for understanding the successes/challenges that students might have had with this complex practice. Table 1 summarizes the student explanations we analyzed for this study.

Classroom Contexts

We selected three classes for this study to achieve diversity in both student body characteristics and enactment. As with the selection of explanatory questions to include in the

TABLE 1
Scientific Explanations From *What Will Survive?* Analyzed

Question	Type of Claim	Evidence Available	Number of Responses
Lesson 6: Construct an explanation "explaining which organism the invasive species competes with"	Students *identify*	Graphs of population fluctuations, created by a NetLogo (Wilensky, 1999) computer simulation	40 responses created by pairs of students
Lesson 7: Construct a scientific explanation describing "the changes in population of the chub, after the sea lamprey invaded"	Students *describe a chain of events*	A food web providing information about how the organisms are related (predator/prey) Graphs of population fluctuations before and after the sea lamprey entered	34 responses created by individual students
Lesson 13: Explain why the majority of finches died in 1977 and why some survived	Students *describe a chain of events*	Data from the Galapagos Finches environment (Reiser et al., 2001; Tabak & Reiser, in press) regarding bird traits, survival rates and environmental conditions	18 responses created by pairs of students

data set, we include each of these classes because of the variety they introduce. That is, the teachers' differing emphases provide a realistic view into how the teachers support the practice of constructing and defending scientific explanations. Moreover, this variety increased the likelihood that student answers would demonstrate a range of ways that students could engage in this practice. Thus, the teacher and school variability provided greater opportunities for us to examine the utility of the three goals for understanding student engagement in the practice of constructing and defending scientific explanations. In this section, we provide an overview of how these classes enacted the unit and their student body characteristics.

The classes selected for this paper each enacted the curriculum differently. More specifically, our overarching goal of facilitating students' participation in scientific practices led us to compare the reasons that students engaged in the practice of constructing and defending scientific explanations, across the classes. As discussed above, this practice combines the goals of sensemaking, articulating, and persuading. Thus, we predicted that having classes that emphasized these goals differently would result in students constructing and defending explanations differently. Table 2 summarizes the different goals that each class discussed when writing and presenting their scientific explanations.

There are a total of 53 students represented in this study: 16 from Classroom 1, 20 from Classroom 2, and 17 from Classroom 3 (for a total of 28 females and 25 males). Classrooms 1 and 2 were from different schools in a suburb of a large midwestern city; one third of the students in each of these schools are African American and one third are eligible to receive free or reduced lunches. Classroom 3, on the other hand, is in that large midwestern city; almost 100% of the students in this school are African American and about two thirds receive free or reduced lunches.

TABLE 2
The Explicit Goals for Writing and Presenting Scientific Explanations in Each Class

	Written Explanations	Presented Explanations
Class 1	No explicit goal emphasized by the teacher; scientific explanations are introduced as a question to answer on the worksheet.	Students presented explanations to share them.
Class 2	Written explanations are a form of scientific report. This teacher mapped the components of an explanation onto the framework for scientific reports with which the students were familiar (e.g., the conclusion of a scientific report is the claim of a scientific explanation). Students are given neither a reason for shifting from "reports" to "explanations," nor a purpose for the "writing."	In Lessons 7 and 13, students presented explanations to one another to pick an explanation to share with the curriculum designers. In this way, the goal was loosely to persuade one another that their explanation was the one to report to the curriculum designers.
Class 3[a]	The class discusses the idea that scientists use explanations to persuade each other of their ideas. They also discuss the idea that empirical evidence is important because, in science, claims can only be true if there is evidence to support them.	Similar to Class 2, students in Class 3 were told that they should choose the explanation that best represented their class' ideas. Thus, this class presented their explanations (in Lesson 7) to persuade one another of them.

[a] This class differs from the others in that they started *What Will Survive?* toward the end of the school year. Consequently, they only had time to work through Part 1 of the unit.

As discussed above, we expected the crossclass variability—both in terms of enactment differences and student body characteristics—to result in differences in how the students constructed and defended scientific explanations. In other words, we chose these classes to see a range of ways in which students could engage in this complex practice. However, the purpose of this study is not to compare the classes' performance. Thus, we compare individual student performance to neither the goals that were emphasized in instruction nor the student body differences. Instead, we hoped that the crossclass differences would reveal a variety of ways that students could engage in constructing and defending scientific explanations.

Data Sources

For each of the three participating classes, we collected daily videotapes, pre/posttests, pre/postinterviews with a subset of the students, and all written work. The researchers largely maintained an observer stance throughout the data collection, occasionally conducting brief interviews as students worked through the lessons and helping the teacher respond to a student question, when necessary. This study focuses on students' written explanations because this is the form emphasized by the curriculum, and we are hoping to examine student work in the most supportive environment. We use the videotaped observations to provide additional information about the context in which the student work occurred.

The written explanations are typically three- to five-sentence paragraphs that are written as responses to a prompt for a "scientific explanation." For example, in Lesson 6, students are asked to construct an explanation identifying the competitor of an unknown organism. Individual students write about half of the explanations in the unit, pairs or groups of students wrote the other half. In the following section, we describe our analytical approach for using these explanations to elucidate the strengths and weaknesses that students had with the practice of constructing and defending scientific explanations.

Analysis Approach

This study investigates challenges and successes that students experience with the practice of constructing and defending scientific explanations. To do this, we analyzed the 92 written responses in our data corpus with the expectation that patterns in how students constructed their written arguments would highlight these successes and challenges. We propose the three goals of sensemaking, articulating, and persuading as a tool to explain the strengths and weaknesses that are exhibited in this data corpus.

Throughout this analysis, our coding scheme emerged out of the students' work. This analysis revealed two very different ways in which students would construct and defend their scientific explanations. In the first, students presented explanations that closely followed the claim, evidence, and reasoning framework provided in the curriculum materials. In the second pattern, students wove these components together in such a way as to make it difficult to differentiate between the claims and evidence. It is important to note that these two types of explanations emerged in all classes and in all three lessons we examined.

Even while many of the responses we analyzed did not clearly differentiate between the claim, evidence, and reasoning components, the students consistently used evidence to develop claims. That is, we found that all the 92 responses had accurate claims (12 of those responses appear to have only partial understandings); this accuracy implies that students were constructing claims that were bound by and aligned with the evidence. This is consistent with the earlier research into the IQWST framework (McNeill & Krajcik, 2007; McNeill et al., 2006) and drove us to focus on understanding the implications of the difference in how the students presented their explanations. Can we use the goals of sensemaking, articulation, and persuasion to explain the two patterns apparent in the students' scientific explanations?

It is possible that weaving these components together is a sensible approach to constructing and defending scientific explanations—it is a natural presentation of the students' explanations. On the other hand, it is possible that this structure highlights challenges facing students as they engage in this complex practice. Our analysis focuses on understanding the implications of these different patterns: What does the way claims and evidence are presented mean with respect to the students' understanding of and success with sensemaking, articulating, and persuading others? To address this, we performed an iterative analysis comparing those explanations that embed the components of claim, evidence, and reasoning with those that clearly delineate them. Through this comparison, we tease apart the characteristics on which the explanations differ and attempt to use the three goals to explain these differences.

Analysis

We begin by providing examples of the two patterns apparent in the students' explanations: those that embedded their evidence and claims and those that clearly delineated them.

Examples of the Two Styles of Explanations. Both of our sample explanations come from students in Class 1 and address the culminating question in Lesson 13. This lesson asks students to synthesize data from a computer database to determine why most of the Galapagos Finches died in the mid-1970s and how some survived the catastrophe. Throughout this lesson, students combine and analyze data showing environmental data, behavioral fieldnotes, and relationships between finch traits and their survival, to construct a scientific explanation solving the mystery. We selected responses from Lesson 13 because it is the most complex explanation that the students constructed—it consequently resulted in the most interesting analyses. The two specific responses below demonstrate similar understandings of this phenomenon while representing the two different styles of communicating these understandings: The first wove together the claim, evidence, and reasoning components, whereas the second clearly delineated them. These examples are prototypical of the two types of responses the students constructed across classes and lessons.

The following example represents a typical response that weaves together the claims, evidence, and reasoning. Although this response is coherent and consistent with the available data, the students did not make clear to readers which parts of their explanation were based directly on their evidence and which were inferences they were defending. In other words, these students do not differentiate between the claims and justifications (in the form of either additional inferences or evidence):

> 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[1] to the Tribulus and be able to eat the seeds without dying. (Classroom 1, Student Group JH, Finch Survival[2])

This explanation is consistent with the available data and the students referenced this evidence throughout their explanation (e.g., the Chamae, Portulaca, and cactus were scarce and the Tribulus had hard seeds). Furthermore, the implicit and explicit connections in this response communicate the students' chain of reasoning (e.g., a drought caused a lack of food, which resulted in increased competition for the few seeds that remained, so most of the birds died from lack of food). Not only is this reasoning logical, but it also applies the appropriate scientific principles regarding relationships between organisms and competition. Thus, in some ways, the students have accomplished the task—they have used evidence and reasoning to decide between multiple possible explanations and to construct a coherent explanation about the finch phenomenon. However, readers who are unfamiliar with the students' problem context and the available data would have a difficult time deciding whether the students' claim is supported by the available evidence. Moreover, this weaving together of claims, evidence and reasoning makes it difficult to identify which aspect of this explanation is new and different; what are these students claiming and how are they defending that claim? Thus, while an audience that is familiar with the students' data could tell that this explanation applies the appropriate scientific principles to understand the available data and tell a coherent story, it is not communicated in a way that supports a readers' scientific evaluation of it.

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[1] These students are clearly not using "adapt" in the strictly scientific sense. In conversations with these and other students, we have learned that these students use "adapt" in this colloquial way to mean that the birds changed what they ate, not that their physical characteristics were changed.

[2] Throughout the student quotes, we corrected the spelling of the plant names (for clarity to our audience) but left the rest of the student grammar and spelling as it was written.

The next explanation exemplifies the second pattern we saw in students' scientific explanations. As with the students in the first example, these students claimed that some birds survived because they ate a specific plant—the Tribulus. After explaining what happened, these students presented the 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 [sic] the Tribulus plant, which didn't effect 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)

Like the first example, this explanation presents a coherent, plausible account of the finch mystery that is constrained by the data. Explanations such as this differ from the ones represented by Example 1 in that the three components of claim, evidence, and reasoning are clearly identifiable in this presentation. That is, the first sentence offers a claim, and the students identify the following three sentences as evidence by using numerical data and using the phrase "research shows." And the last three sentences communicate the reasoning, clarifying the logical connections between the evidence and claim. Thus, as a reader, it is easy to determine what information is new (i.e., the claim), which aspects of the response come from data (i.e., the evidence), and which were the students' supporting inferences (i.e., the reasoning).

In both of these responses, the students constructed a plausible and evidence-based scientific explanation about why so many birds died, but some survived. Thus, both student groups appear to have accomplished the goal of the lesson: They both used evidence to explain the differential survival of some finches. However, the different ways students communicated these understandings raise questions. Why do students use evidence to construct their explanations but do not make the evidence clear when they report it? Do the aspects of sensemaking, articulating, and persuading explain these differences? Motivated by these questions, we examined the data corpus to identify the characteristics that typify these two explanation patterns.

This finer-grained analysis was designed with the expectation that teasing apart the differences exemplified in the above explanations could clarify the connection between these different styles of writing and the three goals of constructing and defending scientific explanations. Through this process, we identified a number of strategies students employed to clearly differentiate their claims and evidence. More specifically, we identified strategies that students used to differentiate between their inferences and evidence. We also identified a second characteristic that differs across the students' explanations: some explanations used "persuasive statements." Persuasive statements are statements such as the one found in the second example above, in which the students said: "According to the information we found, our hypothesis is correct." The function of these statements is to persuade the readers of the author's claims.

In the following sections, we describe the two characteristics of differentiating evidence and claims and persuasive statements. We provide examples of strategies students use to implement these two characteristics, and argue for the importance of each characteristic by relating them to the literature and depicting their representation in the entire data corpus. We conclude by exploring the relationship between these characteristics and the three goals (sensemaking, articulation, and persuasion) to determine how these goals help to clarify the successes and challenges facing students as they construct and defend scientific explanations.

Differentiating Between Inferences and Evidence. In the above definitions of the claim, evidence, and reasoning components, we differentiated between two uses of inferences in explanations: those that are new and are being defended (i.e., claims), and those that are used as support for a claim by elucidating the link between the claim and evidence (i.e., reasoning). In the following analysis, we combine these uses of inferences because the net result of embedding the evidence and inferences is that readers are unable to identify the claim. That is, as seen in Example 1 above, it is difficult to determine which of the clauses is the central claim to be supported, which are evidence, and which are inferences used to connect the claim and evidence. Thus, explanations such as this eliminate the distinction between claims and inferential reasoning discussed above, and we therefore focus on looking for indicators that students have differentiated their inferences from their evidence.

As described in the science education research, the distinction between inferences and evidence is key to the inquiry process (e.g., Driver et al., 2000; Duschl, 2000; D. Kuhn et al., 2000). From a learning perspective, understanding this distinction enables students to identify which aspects of their explanations need additional support, which questions to pursue, and whether alternative claims may be possible. From a communicative perspective, clearly identifying the evidence enables readers to scientifically evaluate the merit of the students' claims.

The students in the Example 1 embedded their claims and the supports for those claims. As a result of this writing style, it is difficult for the audience to determine which information is fact and which information is the result of inferences the students made. For example, examine the following sentence in which we italicized the data that were available to the students: "Since *those plants [Chamae, Portulaca and cactus] 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 to the Tribulus and be able to eat the seeds. . . ." Without being familiar with the students' problem context (including the instructional sequence and computer supports), it is difficult to make the distinction elucidated by the italics. That is, this presentation of the data does not make clear how these students knew that the Tribulus seeds were "harder and lengthier." Are these data that the students found in their research or an inference they made based on reports that only some of the birds ate these seeds? These students have provided little guidance to support the reader in determining what is evidence and what is inference, thereby making it difficult for the reader to evaluate whether the available data support the inferences being made.

While one might assume that students in a class using this program would all be familiar with the data, the Galapagos Finches environment is rich enough for students to pursue different paths through the data and to construct different interpretations of the complex data set. It is therefore entirely probable that each student group looked at slightly different data sets making them "unfamiliar readers" of one another's work. That the community may be unfamiliar with one another's work is consistent with the practice of scientific argumentation in which participants are unable to assume that their audience is familiar with their data. However, this lack of shared evidence means that readers of explanations such as the one in Example 1 may not know what evidence the authors were referencing (if any) when they wrote assertions that moved ambiguously between evidence and inferences. This ambiguity can make it difficult for the students to engage in a discourse in which they evaluate one another's inferences in light of alternatives. In other words, without understanding the distinction between the inference and evidence, students are unable to engage in an argument about the explanation—they cannot evaluate whether they believe that the available evidence supports the claim.

The following section elucidates how we determined whether the explanations differentiated or embedded the evidence and inferences. The scientific explanations we examined reveal two general strategies that students used to differentiate between inferences and evidence. First, they explicitly referenced their data source. The second strategy was to present the evidence in a way that was similar to the data's original form. We used these strategies analytically as indicators of whether students differentiated between their inferences and evidence.

Strategy 1: Explicitly Referencing the Data. The clearest way these students distinguished between evidence and inferences was to explicitly reference the data. In the examples from above, the students accomplished this two ways: (1) naming the evidence source, such as "The charts of cactus, Portulaca, and Chamae all show. . . " and (2) generally referencing the evidence "The research of four birds that survived showed. . . " or "the graph shows that. . . ." These statements mark the information as evidence. That is, by citing these sources, the students have made apparent that the information came from their research rather than their own inferences.

However, these clauses raise a question regarding the apparent simplicity of looking for citations: How precise should the students' citations be? In citations such as the first one, the students told their reader that they were looking at charts and they identified the plants on the charts. Knowing the database with which the students worked enables teachers and researchers to identify the chart that the students were referencing in this sentence. However, in the second more general reference, it is more difficult to identify the students' data source: Which birds have the students examined? At what graph were the students looking? We found that, when using these references to differentiate between the evidence and inferences, the level of specificity in the citation was less important than whether students referenced the data source at all. That is, all data references communicated that the information was empirically based. Thus, as we examined the corpus of scientific explanations, we looked for clauses that identified the information as evidence based, regardless of the level of precision.

Table 3 shows the cues students used to cite a data source. As seen in this table, there exist multiple ways for students to cite their data source and each one of them cues readers that the evidence is a different type of information than the inferences. Thus, our analysis of the student explanations coded for each of these cues to determine the degree to which the students were differentiating between evidence and inference.

In addition to referencing the data source, we found that the ways in which students described the evidence helped clarify the distinction between evidence and inference. That is, presenting the evidence in a form that is similar to that of the original data source helped mark it as distinct. This strategy is presented in the following section.

Strategy 2: Presenting Data in Form That Is Similar to the Original Source. Presenting data in a form that is similar to that of the original data source is the second strategy students used to distinguish between evidence and inferences. In Example 1, from above, the students stated: "Since those plants were very scarce there was one other plant called the Tribulus, which had harder and lengthier seeds. . . ." In this explanation, the reader was not given an opportunity to determine that most of the plant seeds were "very scarce," instead the reader must trust the students' interpretation of the situation. Moreover, this sentence presented an implicit comparison between the "very scarce" seeds and the Tribulus seeds that were "harder and lengthier." This structure implies that the Tribulus seeds were not "very scarce," but the students have not explicitly provided that information. Rather than describing the data in a form similar to that of the raw data (e.g., numbers), these students stated the data

TABLE 3
Markers for Differentiating Between Evidence and Inference

General Strategies	Cues	Frequency (%)	Description	Examples
Referencing data	Identifying evidence sources	17	Clearly identifying where the data came from. When there are multiple possible data sources, students specify which ones they are using	“The charts. . . all show. . . ” (from above) refers specifically to graphs that the students examined. The clause “I looked on my food web and saw. . . ” refers to a specific chart in the student’s binder.
	Referencing evidence, generally	19	Clearly stating that the statement comes from evidence without identifying the specific source	“Research of four birds” does not identify the source of this research “My evidence is that. . . ” identifies the statement as evidence but does not report the data source.
	Bounding statements by referencing time or context	57	This is a weak data reference. It indicates that observation the student is using did occur. That is, to happen at a specific time or context, the event must have happened, and is therefore not an inference.	“When the invasive species was put into the environment. . . ”
	Attributing confidence in the information presented	26	These statements of confidence are a weak reference to data, in which students differentiate between factual evidence and inferred claims. Statements such as this were often used to rhetorically separate the data from the inferences. In these cases, students are not explicitly referencing their data sources, but they have highlighted the evidence and inferences as two different types of knowledge.	“I know this [the claim] because [evidence]” “[Evidence] means [claim]” “I think [claim]” “. . . There was a nice size number of foxes and invasives [sic] but the rabbit and grass populations were pretty low. *I believe* that the rabbits couldn’t have eaten all that grass if they were leaving so quickly.”
Presenting data in a way that is similar to the original	Using numbers, numerical descriptions, making clear comparisons	52	Descriptions of data that imply that the information is empirical	“. . . the weather station had no inches of rain recorded in the dry of ’77.”

as though they were an inference, effectively disguising the fact that they were working with data at all. This presentation provides the audience with an incomplete understanding of the information available, thereby making the reader unable to distinguish between the pieces of the explanation that are based on evidence and those that are inferences.

Example 2, on the other hand, provided the actual numbers, thereby describing the data in a form that is closer to the original. This allows readers to assume that the information came from a data source. For example, in the sentences: “The charts of cactus, Portulaca, and Chamae all show a major decrease to 0, 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,” the readers have access to all of the information used in the comparison. That is, in this example, the reader is given a sense of *how much* the Tribulus seed count differed from the others (e.g., it decreased, but not all the way to 0).

As with referencing data, the degree to which data are presented in a manner similar to the original source is a continuous variable. The following two examples demonstrate the ends of this continuum, as seen in student responses. For both of these examples, the students were working with a NetLogo computer model (Wilensky, 1999) of a simple ecosystem that contains foxes, rabbits, grass, and an unknown invasive species. The students used graphs of the population fluctuations to determine which of the other organisms the invader eats.

In response to this question, student EJ stated:

> . . . This invasive species eats *grass effecting* [sic] *the grass and the rabbits in a bad way but the foxes in a good way*. The rabbits have to compete for grass and foxes have more food.” (Classroom 1, Student EJ, Lesson 6)

In the italicized segment, the student was referring to the available data—the grass and rabbit population decreased, while the fox population increased. However, by saying that the grass and rabbits have been affected “in a bad way,” this student made it difficult for a reader to recognize that he looked at the graphs and was talking about population sizes. A reader who was unfamiliar with the context could easily assume that the student was referring to the rabbits’ quality of life, rather than the population size. This is an example of a response that presents the information in a form that bears no relation to the data itself, thereby blurring the distinction between the inferences and the data.

Student EL, on the other hand, differentiated her evidence by describing what happened on the graph:

> The invasive species was competing with the rabbits for grass. When we put the [invasive] species in the environment, *the graph shows that the rabbit and invasive species both went down at about the same time and while they were both down, the grass went up.* I think the reason for those rises and falls is that both the rabbits and the invasive species eat grass. (Classroom 2, Student EL, Lesson 6)

In the italicized sentences, this student described changes in the population sizes. While this is an interpretation (she did not provide the raw numerical data), it is closer to the original data and therefore allowed the readers to construct a relatively clear picture of the relationships in her data set. Thus, explicitly describing the graph helped this student to differentiate between her evidence and inferences.

As these examples demonstrate, presenting evidence in a form that is similar to that of the data source is a strategy that helps the reader identify the students’ evidence and, subsequently, to evaluate the claims. When evidence is presented in a from that is not clearly connected to the original data source, such as the evidence seen in the first example from both the finch and ecosystems lessons, it is difficult for readers to determine that the information came from student observations or other data source. That is, if presented in a form that is removed from that of the original data source, the data are often indistinguishable from the students' inferences. Thus, similar to the idea of explicitly citing the data source, presenting evidence in a form that aligns with the form of the original data source can help readers identify which parts of the scientific explanation are based on evidence and which are not.

Table 3 summarizes these two strategies of referencing data sources and clearly presenting the data, including descriptions of the cues for each of these strategies and the frequency with which each cue appeared in the data set.

Note that these strategies are not mutually exclusive. That is, a single explanation could have multiple pieces of evidence, each of which could identify the evidence as evidence in different ways, if at all. (This means that each explanation could be coded multiple times, and the percentages with which each cue appeared in the data corpus therefore add up to more than 100%.) Similarly, a response may contain evidence that is presented in a form similar to that of the data source (thereby implying that it is evidence), but not cite the source. Thus, these two strategies of citing evidence sources and presenting evidence in a form that is similar to that of the raw data guided our determination of how differentiated the evidence and inferences were, but we made the final decision based on a holistic judgment about how identifiable and distinguishable evidence and inferences were in the explanations.

Through this, we found that 45% of the student responses embedded their evidence in their inferences, 46% clearly differentiated them, and 9% of the responses were middle-ground cases. Looking at individual classes reveals that between 35% and 49% of the explanations in each class had embedded evidence and inferences. Thus, across classes we see that embedding evidence and inferences was a common pattern in the students' scientific explanations. As this type of scientific explanation makes it difficult for the audience to evaluate the explanations, it may suggest that the creators of these types of explanations were not explicitly attending to the goal of *persuasion*, in which audience evaluation is key. That is, since embedding evidence and inferences make it difficult for audience members to determine whether they are persuaded by an argument, writing this type of scientific explanation may imply that the authors are not attempting to achieve the goal of *persuasion*.

We investigated this possibility by examining the second characteristic we identified as varying across the student work: persuasive statements. By definition, persuasive statements are explicit attempts to *persuade* readers and therefore imply that the authors of explanations that contain these statements were attending to *persuasion*. In the following section, we investigate the relationship between these two characteristics.

Persuasive Statements. A convincing argument often tells the readers why to believe the claim. For example, a student may say "this explanation is true because. . . ." O'Neill (2001) calls these "overt persuasion" statements. We found the degree to which students attempted to overtly convince their readers to be another characteristic that differed across explanations such as those represented by Examples 1 and 2. For instance, in Example 2 from above, the students linked their evidence regarding the Tribulus plant's survival to the survival of finches that ate it, by saying:

> Which means that the drought didn't effect [sic] the Tribulus plant, which didn't effect 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)

Note the penultimate sentence in the students' reasoning: "According to the information we found, our hypothesis is correct." Student EJ also included a persuasive statement when she concluded her explanation by stating "... this proves that the invasive species eats grass" (Classroom 2, Student EJ, Lesson 6).

These persuasive statements are not a requirement of the IQWST instructional framework. That is, one can succeed at fulfilling the claim, evidence, reasoning framework without including a persuasive statements. This means that students had no reason to say "our hypothesis is correct" unless they are attempting to persuade the reader. Thus, we contend that the use of persuasive statements indicates the students' attention to the third aspect of argumentation, that of *persuading* others of their understandings.

About 30% of the scientific explanations in these data corpus included this characteristic. In the following, we relate the two characteristics we have discussed: differentiating between evidence and inference and writing overtly persuasive statements. This comparison reveals that when students differentiated between their evidence and inferences they were more likely to include persuasive statements. We conclude the paper by discussing this relationship and attempt to use the goals of sensemaking, articulating, and persuading to explain this relationship.

Comparing the Characteristics in the Data Corpus. Table 4 presents the structural characteristics described above, summarizing our analysis of the examples with which we opened our investigation.

Examining the entire data corpus demonstrates that this pattern of characteristics is not uncommon. That is, as Table 5 shows, students were more likely to include persuasive statements in responses that differentiated between the evidence and inferences than those that embedded them.

The two characteristics are significantly related ($\chi^2 = 6.23$, $p < .05$). That is, explanations with differentiated evidence exhibited an increased likelihood that they would contain persuasive statements over those with undifferentiated claims and evidence. This relationship is interesting because the use of persuasive statements is not required when differentiating evidence and inferences. That is, as seen in Table 3, none of the strategies students used to differentiate their evidence and inferences required that they include

TABLE 4
Summary of the Characteristics in Each Example Explanation

Characteristics	Explanations Such as Example 1: Embedded	Explanations Such as Example 2: Differentiated
Embedded vs. differentiated evidence		
Referencing data sources	No references or citations	Names two different data sources
Similarity between raw data and data presentation	Dissimilar: comparing "scarce" seeds to "harder" seeds without defining these dimensions	Highly similar: providing relative descriptions (e.g., "quite low but not enough to disappear all the way")
Use of persuasive statements	No persuasive statements	States: "According to the information we found, our hypothesis is correct."

TABLE 5
Comparing the Level of Differentiation Between Evidence and Inference to the Presence of Persuasive Statements in the Students' Work

	No Persuasive Statements	Contains Persuasive Statements	Total
Embedded evidence and inferences	35	7	42
Partly differentiated evidence	6	3	9
Differentiated evidence	24	17	41
Total	65	27	92

persuasive statements in their answers. Thus, this relationship suggests that the overt attention to audience—as demonstrated through persuasive statements—is associated with student attention to the differentiation of their evidence and inferences. In our discussion, we focus on what these two characteristics, and the relationships between them, reveal about the ways in which students engage in the goals of sensemaking, articulation, and persuasion by constructing and defending scientific explanations.

DISCUSSION

We began this paper with the general goal of understanding the strengths and weaknesses that students exhibit when engaging in complex practice of constructing and defending scientific explanations. We proposed that decomposing this practice into the three goals of sensemaking, articulating, and persuading could help identify and explain these challenges. We examined students' successes and challenges in the context of an IQWST unit that is designed to support students with this complex practice by structuring how students articulate their final products to influence students' sensemaking and persuading processes. Through the analysis of student work, we described the differences between the students' explanations in terms of two characteristics: (1) the level of differentiation between evidence and inferences and (2) the use of persuasive statements. We found that students were significantly more likely to include persuasive statements when they also differentiated between their evidence and inferences. We now turn to the three goals of constructing and defending a scientific explanation to understand the implications of the observed challenges in students' explanations.

First, the students' explanations appear to consistently fulfill the sensemaking aspect of constructing and defending scientific explanations. We see this in the accuracy rate of the students' explanations: Each of the explanations examined in this data set presented claims that were logically bound by the evidence provided. This indicates that students were using the evidence to successfully make sense of the phenomenon under study. These explanations also demonstrate students' success with the second goal: These students successfully articulated their understandings. These explanations presented scientifically plausible coherent causal chains to account for the result to be explained. That is, regardless of whether the evidence and inferences were clearly distinguishable, the explanations clearly conveyed the students' understandings of the phenomenon under study. Thus, it appears that, as previous research on this explanation framework has shown, highlighting the components of claim, evidence, and reasoning helped the students ground the sensemaking in evidence and to articulate those understandings (McNeill & Krajcik, 2007; McNeill et al., 2006).

In addition, we saw some evidence of student attention to the goal of *persuasion*; we suggest that the characteristics of differentiating between evidence and inference and using persuasive statements are both related to this third goal. The persuasive statements indicate explicit attention to persuasion because the sole function of these statements is to say: "believe me." Similarly, explicitly differentiating between the evidence and inference suggests attention to this goal of argumentation because clearly identifying claims and evidence enables readers to evaluate whether the evidence supports the claim. These actions suggest an attempt to make clear why the audience should believe the inferences presented in the causal chain by making clear the evidentiary support for the inferential steps in the chain. Together these two actions in crafting explanations suggest that the student authors were focusing on the goal of making their explanations not only coherent and consistent with data but also persuasive to their audience.

Yet we also found challenges in these explanations. Fully half of the explanations included ambiguous statements in which explicit evidence drawn from the data and inferences drawn from that evidence were not clearly distinguishable. To an authentic audience, not familiar with the data the authors investigated, these explanations would be unclear as to what the authors had seen and what speculations they had drawn from it.

Thus, student authors of explanations that embedded the evidence and inference did not fulfill the goal of persuasion because they did not support their audience in evaluating whether they were persuaded. 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 this goal. D. Kuhn and colleagues (1989, 2000) have argued that students have trouble coordinating "evidence and theory" because they have trouble disentangling the demands of empirical support and plausibility. However, we found that even those explanations that exhibited ambiguous evidence were constrained by the evidence, thereby revealing that these students were clearly attending to their interpretations of the evidence in developing their explanations. This suggests that these students knew that evidence is an important aspect of scientific inquiry.

Thus, rather than an inability to distinguish between inferences and evidence, we suggest that students' observed difficulties with evidence and inference stem 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 an explanation may have been to demonstrate that they knew the "right answer" to their teacher. Alternatively, if these students did think of their peers as a potential audience for their explanations, they may have viewed them as an audience who were familiar with the data, and therefore did not require the authors to carefully elucidate their claims and evidence. We contend that, unless students genuinely took on the goal of trying to persuade others, who did not 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. According to this view, students who produce explanations ambiguous in their evidentiary support are attempting to demonstrate an accurate understanding, without attempting to convince their readers that their causal account aligns with the available scientific support.

The observed relationship between the persuasive statements and embedding evidence and inference supports this understanding of why students would embed their evidence and inferences. Students were more likely to use explicit persuasive statements when they differentiated their evidence and inferences than when students embedded them. This association indicates that there may be an underlying variable mediating the students' writing. We suggest that the goal of persuasion is that variable. That is, attention to the goal of persuasion may motivate students to both make overtly persuasive statements and clearly differentiate between their evidence and inferences. Therefore, we contend that while explanations such as Example 1 fulfill the first two aspects, they do not satisfy the final aspect of persuading others of their newfound understanding.

This analysis reveals a critical way in which some learners' engagement in the complex practice of constructing and defending scientific explanations can depart from the target practice: It appears that they are not consistently attending to the goal of persuasion. That is, the challenges that students face in constructing and defending scientific explanations—their lack of differentiation between evidence and inference—suggest that, while students seemed to use evidence when engaging in the sensemaking, they were less careful in persuading others of that understanding. In the following sections, we discuss why challenges to this third goal may emerge, and we propose design strategies for addressing these challenges.

Why Would This Happen?

This third goal of constructing and defending scientific arguments draws centrally on the social nature of the practice. That is, the act of persuading carries with it the social expectations that individuals have an audience for their arguments, that this audience will interact with the presenters to determine whether they are persuaded of one another's ideas, and that the audience may not have had the same experiences and beliefs as the authors of the argument. These social expectations indicate that engagement in persuasion requires that students attend to the audience for their arguments.

Indeed, attending to an audience that is unfamiliar with the students' work is counter to typical interactions in science classrooms. In fact, getting students to consider why an audience should believe and be persuaded of ideas, rather than taking on the task of reporting "correct" answers, is a core challenge of bringing authentic practices into science classrooms (Duschl et al., 2007; Jimenez-Aleixandre et al., 2000). In most typical classrooms, the true audience for the work is the teacher, who will evaluate whether the student has demonstrated understanding. Moreover, as many researchers have observed, the typical science classroom presents science 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). That is, typical classroom interactions may not support the teachers and students in establishing the social or epistemological expectation that constructing scientific understandings is a complex process in which the students are key participants (Brown & Campione, 1996; Cornelius & Herrenkohl, 2004; Engle & Conant, 2002; Hogan & Corey, 2001; Scardamalia & Bereiter, 1994). Thus, we contend that the challenge that students face with attending to the goal of persuasion emerges from the apparent conflict between the expectations inherent to this goal and the traditional norms of the classroom: Traditional classroom norms do not provide a reason for students to use evidence to persuade an audience of their ideas.

Design Implications

Supports such as the IQWST claim/evidence/reasoning framework attempt to provide students with a model of an explanation, thereby supporting their sensemaking and persuasion through their articulation. The IQWST framework does this by identifying the types of knowledge that are necessary when engaging in the practice of constructing and defending scientific explanations. However, our work reveals that this framework does not appear to address the social challenges facing students when engaging in the third goal, that of persuasion. While we can teach the components of an effective explanation, really taking on the goals sensemaking, articulation, and persuasion requires more than just knowing the parts of an explanation; it requires taking on a new goal of persuading a neutral audience, who does not know the particular results of the work of the authors. This requires different classroom norms, including seeing science as building knowledge with peers; expecting to have to defend ideas against alternatives from peers; and reaching consensus, rather than just being responsible for obtaining "right answers" from the authorities of teachers and textbooks. Thus, the design challenge is to extend the supports for constructing and defending scientific explanations to address these social challenges.

We began this paper discussing two strategies for supporting student engagement in constructing and defending scientific explanations. The second—structuring student articulations to guide their sensemaking—is the approach taken by the IQWST curriculum used in this study. The first—creating opportunities for students to make sense of phenomena through persuasive discourse—illustrates one approach to addressing the challenge faced by students in this study. These design creating opportunities for persuasion by putting students' ideas in opposition and facilitating their reconciliation (Hatano & Inagaki, 1991; Osborne et al., 2004).

Building on Edelson's design framework, Learning-for-Use (2001), we see the importance of going beyond creating these opportunities by making persuasion necessary. That is, Edelson's work suggests that the content students are learning must have a 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. Applying this to the practice of constructing and defending scientific explanations indicates that to successfully engage in this practice, each goal—sensemaking, articulating, and persuading—must have a purpose. Thus, we propose extending these approaches to emphasize the necessity of the goal of persuasion.

Engle and Conant's design principles work together to create a purpose for each of these goals (2002). Building on Brown and Campione's work in Fostering Communities of Learners (1996), Engle and Conant's design principles enable students to participate in persuasion by asking students complex questions that require them to break into teams such that each team will develop expertise in specific area of the problem, providing students with sufficient resources to investigate the topic, and creating activity structures that enable students to attend to one another's ideas (e.g., jigsaw groups). We contend that the complex questions make sensemaking purposeful and the group work makes articulating necessary. Moreover, the combination of distributed expertise and jigsaw groups may motivate students to persuade one another; as seen in Engle and Conant's study, it successfully creates situations in which persuasive discourse occurs.

Thus, Engle and Conant (2002) and Brown and Campione's (1996) principles are a useful step in creating a purpose for the goals of sensemaking, articulating, and persuading. However, we suggest that applying Edelson's Learning-for-Use framework (2001) requires designing situations in which these goals are not only enabled but also *necessary*. That is, if we are going to provide students with an authentic reason for to fully engage with this complex practice, then we must create environments in which students have an explicit reason to attempt to persuade their audience; in which success in the activity requires attention to this goal.

The next iteration of IQWST curricula attempts to provide students with a reason to persuade their audience by creating activity structures that place students in the role of audience for one another's arguments. Using this design strategy, we go beyond telling students to interact with one another by engineering situations that give students a reason to attend to whether they are persuaded of one another's ideas, and whether they have successfully persuaded their classmates.

We contend that aligning the goals of the activity with the goals of the constructing and defending scientific argumentation will motivate and enable students to attend to all goals of this practice, including persuasion. However, this approach does not standalone. The structural support provided by scaffolding, such as the claim/evidence/reasoning instructional framework, provides students with a language and criteria for engaging in the argumentative discourse. Moreover, we have seen that this framework supports students in fulfilling the first two aspects of the practice—sensemaking and articulating. Thus, it is the combination of these design strategies that will foster students to engagement in the practice of constructing and defending scientific explanations.

APPENDIX: OVERVIEW OF *WHAT WILL SURVIVE?*

Part 1: How Do We Stop an Invasion?

Part 1 consists of eight 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 one. 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 nonnative ecosystem. They study the functions that an organism's structures serve to allow it to survive. They then dissect the sea lamprey 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.

Learning Set 3: 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.

Learning Set 4: 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 natural selection. Students spend most of Part 2 in a computer environment called The Galapagos Finches in which they explore real data 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.

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