# STUDENTS CONSTRUCTING AND DEFENDING EVIDENCE-BASED SCIENTIFIC EXPLANATIONS

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## ABSTRACT

Constructing scientific explanations is an essential aspect of engaging in scientific inquiry in classrooms (Driver, Newton, & Osborne, 2000; Sandoval, 2003). The IQWST units are designed to teach scientific principles and the scientific practices of constructing and defending explanations, by providing students and teachers with a framework that clearly defines this complex practice. This framework includes the three components of claim, evidence and reasoning. Our study analyzes student work using this instructional framework, in light of the curricular goals we would like students to achieve: 1) *make sense* of the phenomena under study, 2) *articulate* that understanding and 3) *defend* the understanding to one's peers. Through this analysis, we find that the instructional framework supports students in using evidence to make sense of the phenomenon under study but that the students are not clearly articulating the relationship between the evidence and inferences, in their explanations. We conclude the paper with possible design strategies for supporting students as they use differentiated evidence and inference to defend their explanations.

## INTRODUCTION

The goal of science is to construct, evaluate, and refine explanatory models (Duschl, 1990). In the last two decades, two related themes of science education reform have emerged from this focus on science as explanation. First, reforms call for conceptual understanding and reasoning about mechanisms to be cast as the goals for science learning (Linn, Songer, & Eylon, 1996; Smith, 1991; Strike & Posner, 1985). Second, scientific inquiry is thought to be core to science learning, in which students develop and argue for explanations through their own investigations (AAAS, 1990; Blumenfeld et al., 1991; Duschl, 1990; NRC, 1996). In this literature, explanations are both the goal of the activity and the means to get there – that is, students construct explanations in order to understand the phenomenon and as a motivation and guide for engaging in the inquiry process (de Vries, Lund, & Baker, 2002; Driver et al., 2000; Duschl, 2000; Osborne, Erduran, & Simon, 2004; Sandoval & Reiser, 2004). As each of these authors discuss, constructing explanations is a complex practice that incorporates many different types of activities. Moreover, constructing and discussing explanations is hard for students – it requires that they use their evidence to evaluate and revise their claims, connect their evidence to the relevant scientific principles and effectively communicate these understandings. Current reform efforts attempt to characterize the nature of the challenges that students face when constructing and communicating explanations and to design supports that address these challenges (e.g., Hogan & Corey, 2001;

Jimenenez-Aleixandre, Rodriguez, & Duschl, 2000; Palincsar, Anderson, & David, 1993; Sandoval & Reiser, 2004; Toth, Suthers, & Lesgold, 2002).

This study is part of the IQWST research and design initiative in which we design, enact and research middle school science curricula designed to support scientific practices of explanation and argument as learners engage in project-based investigations (Krajcik & Reiser, 2004; Reiser, Krajcik, Moje, & Marx, 2003). The IQWST team has currently created two 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). Part of this process was to create an instructional framework that supports learners in using evidence to construct and defend their scientific explanations, in both content areas. This framework was designed to support students as they engage in both the inquiry process of figuring out what is going on and the act of communicating this understanding. In this paper, we examine whether and in what ways students working with the IQWST biology unit use the instructional framework in their written explanations, and how these responses reflect the different aspects of constructing and communicating an explanation. In this work, we are attempting to understand the different aspects of producing and communicating a scientific explanation, the challenges that students face when doing so and how curriculum materials can support this process.

## UNPACKING THE PRACTICE OF EXPLAINING

Examining the science education research and philosophy of science literature reveals the many different aspects and meanings of the practice of "explaining." At the most general level, we can examine what an explanation is – the product. From this perspective, an explanation is commonly defined as a causal account of how or why something occurred (e.g., Horwich, 1987). Science education researchers add to this more general definition by specifying that the causal accounts must be linked to evidence (Bell & Linn, 2000; Duschl, 2000; Osborne et al., 2004; Sandoval & Reiser, 2004). Nagel (1979) also focuses on the product of explaining. As well as emphasizing the importance of evidence, Nagel adds a taxonomy of explanation types – each of which uses different reasoning patterns to answer the question "why": deductive, mechanistic, genetic and probabilistic.

A second theme that emerges out of this work is a focus on the process of explaining. For example, De Vries et al. (2002), highlight the sense-making aspects of the practice, stating that "in order to explain, students have to externalize, but also to clarify, organize and restructure their knowledge" (p. 68). Similarly, science standards (AAAS, 1990; NRC, 1996) emphasize the importance of having students use logic and evidence to develop explanations.

Current views of science emphasize the role of a scientific community in the scientific knowledge building process, in which scientists propose and thereby test their ideas in their community (e.g., Duschl, 1990). This perspective on science as knowledge building in a community adds to the process and product based definitions by suggesting the importance of examining the social interaction aspects of constructing explanations (Herrenkohl & Guerra, 1998; Hogan & Corey, 2001; Scardamalia & Bereiter, 1994; Tabak & Baumgartner, 2004).

De Vries et al. (2002) provide a useful framework to characterize these various elements of explanation, and described three potential contexts in which students could explain: First, students explain an occurrence to themselves – using the explanation as a sense making opportunity. Second, explanations are a social, communicative practice in which students share their understandings with one another. Finally, scientific ideas need to be tested in a social process of discussion and debate. De Vries et al. (2002) used the term "argumentation" to discuss explanations that are used in this persuasive, disputed context in which individuals are attempting to convince one another of their explanations.

The IQWST team drew from each of these aspects and definitions of "explanation" to construct our instructional supports for the practice of constructing and communicating explanations (Bruozas et al., 2004; McNeill et al., 2004). The IQWST materials are designed to support three related curricular goals encompassed in the single practice of 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* in terms of the evidence gathered and relevant scientific ideas and (3) *defending these understandings* by explicitly connecting the specific evidence and general principles about the relevant scientific concepts to the knowledge claims. While each of these curricular goals are related, it is important to recognize their individual importance.

First, students must *make sense* of the phenomena they study and experience. For example, in the IQWST biology unit, students are asked to use population and trait variation data to explain why some birds survived a drought while others did not. Doing this in a way that is consistent with scientific inquiry requires that students connect the scientific ideas, to which they are being introduced, with the evidence they have collected, and their prior conceptions and experiences (Driver et al., 2000; Jimenenez-Aleixandre et al., 2000). This process is a key component of students developing a deep-content understanding, rather than a more surface memorization of facts (Coleman, 1998).

The second sense of "explain" seen in the literature is to *articulate* one's understandings about what or why an event occurred. That is, students must put their understandings into a coherent expression in discourse. Lemke (1990) argues for the importance of this focus on communication, concluding that one understands something only when they understand the ways in which the idea can be communicated. Other science education research agrees with this focus on communication — it is through communication that students have opportunities to identify the strengths and weaknesses of their understandings (Bell & Linn, 2000; de Vries et al., 2002; Sandoval, 2003; Scardamalia & Bereiter, 1994). Thus, this second goal of *communicating* one's understandings through scientific explanations is one step in the development of community-supported reflection on the students' developing understandings.

Finally, moving beyond an articulation of understandings, students should engage in persuasive discourse, *defending* their explanations. Scientific inquiry is fundamentally a knowledge building process in which explanations are presented to the community so they can be critiqued, debated and revised. Thus, in order to engage in similar scientific knowledge-building practices, students must participate in the collaborative, persuasive discourse of consensus-building. This persuasive discourse goes beyond communicating explanations, engaging students in arguing for them, receiving critiques, and revising their ideas (Carey & Smith, 1993; Driver et al., 2000; Duschl, 1990, 2000). Moreover, argumentation or persuasion has been seen to foster student engagement with the learning process and therefore engagement with the content under study. For example, Orsolini and Pontecorvo (1992) found that disagreement, as fostered through a persuasive discourse, motivated their students (in this case kindergartners) to be more explicit and articulate about their thinking. Similarly, D. Kuhn and Udell (2003) found that engaging in argumentative discourse strengthened the quality of the students' (in this case, inner-city 8$^{th}$ graders) articulation of their beliefs.

Clearly, this final goal of *defending* is an extension of the goal that students *articulate* their understandings. That is, *defending* an understanding is one way that one could *articulate* it. However, these goals are not equivalent. One can imagine a student communicating an understandable and plausible explanation without addressing this third goal of persuasion. Attending to the *defense* of their understandings, means that students will *articulate* why the reader should believe the explanation, given the evidence.

As stated, these seem like three separate goals, but they are intimately connected. To put it simply, what does it mean to understand an event if one cannot explain it (Lemke, 1990)? Thus, the instructional supports were designed to engage students in all three of these goals simultaneously. While one clearly can't *articulate* or *defend* an understanding until one has *made sense* of the phenomena, the IQWST design is intended to influence the students' *sense making* process (goal number 1) by providing a structure for their *articulation* and *defense*. Thus, rather than viewing these goals as sequential, they should be considered mutually supportive aspects of the single practice of constructing and defending an explanation.

Given these goals of *sense-making*, *articulating* and *defending*, there exists an added layer of complexity to what the students must learn. That is, beyond understanding the scientific theories and their application, students must now think about communication; students must learn how to effectively articulate and defend their understandings. Thus, the IQWST materials are designed to include pedagogical supports that enable students to address each of these goals.

### IQWST Instructional Framework

Duschl (2000) argues for the importance of making the nature of science explicit to students by providing them with opportunities to experience the relationship between evidence and theories[1]. He and other authors maintain that it is necessary for students to understand that scientific theories are constructed by a careful examination of the available data in light of the pervading scientific ideas (e.g., Driver et al., 2000). In this vein, Toth et al. (2002) designed and researched the Belvedere software to help students distinguish between their hypotheses and the evidence that supports them. When working in this environment, students record and connect the evidence they collect with the hypotheses they generate. Distinguishing between and connecting

[1] Note that researchers have differed in their focus on "theory," "hypothesis," or "explanation." While there are important differences in these constructs, for our purposes they all share a focus on ideas that learners have constructed, in contrast to empirical evidence. Thus, although we focus on explanation in the present work, research findings that describe challenges for learners in distinguishing theory and evidence or hypothesis and evidence are directly comparable to our contrast between assertions or claims in an explanation and the evidence that can support or refute them.

information that fulfills these epistemic categories is one way of making the nature of science explicit.

Similarly, Sandoval and Reiser (2004) designed curricula and software to make clear the elements of the nature of science for students. These authors focused on "epistemological commitments" or "beliefs about what counts as valued and warranted scientific knowledge" (p. 347-348). With this focus, Sandoval and Reiser were also highlighting the relationship between explanations and evidence by designing supports to help students learn the ways in which scientific knowledge is constructed and defended. That is, their software engages students in an explanation construction process in which the students are prompted to use existing scientific ideas to guide the selection and evaluation of data. This software focuses students on what to communicate when explaining a phenomenon in terms of natural selection by providing students with guiding questions that break the explanation down into the necessary elements. Palinscar et al. (1993) implemented similar supports for sixth graders as the students explained the process of dissolving sugar in water. In this design study, the researchers provided students with three questions highlighting the pieces of information that a scientific explanation about kinetic molecular theory must provide (e.g. identifying the substances being studied).

Each of the design approaches presented by Sandoval and Reiser (2004), Palinscar et al. (1993) and Toth et al. (2002) address Duschl's (2000) concern that students must explicitly learn the relationship between evidence and knowledge claims such as theories and explanations. That is, each of the above approaches creates supports that engage students in the use of evidence and theory in order to make these epistemic categories explicit. There are some differences between these approaches: 1) Toth et al. (2002) use content general prompts and the others use prompts specific to the topic at hand and 2) Sandoval and Reiser (2004) and Toth et al. (2002) focused on software supports while Palinscar et al. (1993) attempted to affect classroom discourse patterns. However, even with their differences, each of these designs share a common design principle of making the epistemic categories of theory and evidence explicit in the students' work, in order to influence the students' inquiry process.

IQWST designed and tested an instructional framework represented in two project-based units, that builds on these design approaches (Bruozas et al., 2004; McNeill et al., 2004). First, as with Sandoval and Reiser (2004) and Palinscar et al. (1993), the IQWST instructional framework makes explicit the practice of "explaining," supporting the students as they communicate their product. However, unlike these approaches, the IQWST framework is designed to be general, rather than to address the specific questions that the students are answering. Further, as seen the designs presented above, there exists an important distinction between knowledge claims and their justifications (Duschl, 2000; Toth et al., 2002). The IQWST framework also highlights epistemic categories by breaking the practice of constructing and communicating an explanation down into its essential elements. In the IQWST case, in order to address each of the curricular goals defined above, the framework highlights scientists' use of evidence and justifications when constructing and defending claims. In order to do this, the IQWST design team drew on Toulmin's argumentation model (1958) to create an instructional framework that makes explicit the importance of evidence and justification. This model contains three components:

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

The IQWST team chose to highlight justification as well as evidence in order to help direct students' attention to the goal of persuasion. In addition, these content general categories were chosen over question specific prompts for two reasons. First, much like the design approaches discussed above, highlighting these types of information helps make the epistemic commitments of scientists more apparent to the students. For example, in order to communicate the importance of evidence, the instructional framework highlights the general requirement that an explanation must contain evidence for its claims. Second, the IQWST framework is the result of balancing the design goals of introducing students to the complex practice of developing and defending explanations while creating a pedagogical tool that is both useful and flexible enough to cover a range of scientific disciplines.

The IQWST units introduce and define these components, support whole class discussions around them and provide scaffolds in the written materials, highlighting any discipline differences that emerge. The general definitions of each of these components remain consistent across the units. In the following, we provide the general definitions and rationale for each component.

CLAIM: The *claim* answers what or why something happened; it is an assertion or testable statement about the phenomenon under study. In the pilot tests 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., 2003). 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 the chub 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. In both of these cases, students must identify patterns in the available data in order to construct these claims.

EVIDENCE: Science is an empirical endeavor. As stated by Driver et al. (2000), "Scientists hold a central core commitment to evidence as the ultimate arbiter between competing theories" (p. 297). Thus, the IQWST instructional framework includes an evidence component, defining it as the scientific data that students gather and combine in order to construct and defend their claims. As designed, evidence could take a number of forms from traditional numerical data (e.g. changes in population sizes) to background information (e.g. the Tribulus seeds are harder than Portulaca seeds) to observations (e.g. sea lamprey have millions of eggs, as seen in a dissection) to facts that were revealed in readings and discussions (e.g. the sea lamprey eats the trout). In order to fulfill the evidence component students must identify the relevant evidence, as it is distinct from their reasoning and claims. Therefore this component is a step towards making the relationship between evidence and theory explicit to students.

REASONING: A key challenge to designers of inquiry curricula is to design supports that promote reflection instead of simply "doing" the activity (Barron et al., 1998; Jimenenez-Aleixandre et al., 2000). Further, 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 et al. 2003). Given these challenges and working with the belief that stating the scientific principles used when reasoning through a problem would foster "deep understanding" (Barron et al., 1998; Windschitl, 2001), "reasoning" became the third component of the instructional framework. In the curriculum, reasoning is defined as "the scientific background knowledge or scientific theory that justifies making the claim and choosing the appropriate evidence" (Bruozas et al., 2004; McNeill et al., 2004). This element makes apparent the disciplinary expectation that the claim be connected to the evidence. As with each of the components, the reasoning is intended to provide students with an opportunity to articulate their understandings, thereby revealing any logical disconnects.

It is important to note the interconnectedness of these components. For example, refining the reasoning could require a student to revisit the evidence they selected and the conclusion or claim they are making. Moreover, after constructing a claim and stating supportive evidence, it is possible that students would need to refine their understanding of the general science concepts under study in order to articulate the appropriate principle. Thus, this model 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' process of constructing explanations.

Using this framework as a guide, students construct explanations, engage in activities that make apparent the three components and discuss how to fulfill the components in various contexts. Through these activities and discussions, the IQWST framework highlights the necessity that students consider both 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 *defending* a claim. Thus, similar to the design approaches discussed above, the instructional framework structures how students *articulate* and *defend* their explanations, in order to influence their *sense-making* process.

Constructing and defending explanations is hard for students and adults, alike. D. Kuhn, Black, Keselman and Kaplan (2000) conclude that students have a difficult time coordinating their evidence and their claims, and that students often maintained their hypotheses in the face of disconfirming evidence. Similarly, in early versions of IQWST, students provided claims and causal accounts without connecting them to evidence or general principles. Initial studies into the effectiveness of the IQWST framework find that the framework does support students in stating supportive evidence and reasoning in the IQWST chemistry unit (McNeill et al., 2003; McNeill & Krajcik, in press).

In the current study, we explore the ways in which the framework supports students in achieving the three goals of *sense-making, articulating* and *defending* while explaining biological phenomena. Through this exploration, we attempt to uncover the aspects of the three goals that the students fulfill. To do this, we examine how students' responses reflect the instructional framework, looking at whether and how these answers achieve these three goals. We begin by providing more specifics about the *What will Survive* unit, and then move into our analyses.

## CURRICULUM

The IQWST project designs project-based units in which the scientific ideas are contextualized in driving questions that the students investigate throughout the unit (Blumenfeld et al., 1991; Edelson, 2001; Singer, Marx, Krajcik, & Chambers, 2000). The driving question supports the students in engaging in longer-term investigations; a single driving question can sustain a 4–8 week unit with sub-questions that are used for activities that last from 1-day to two weeks. Through these investigations, students are asked to apply scientific concepts in order to understand the data they are examining. For example, students use ideas about predator/prey relationships and competition to determine how the sea lamprey (an invasive species) affected the native fish populations in the Great Lakes. Given this pedagogical strategy, in the IQWST units, explanations that bridge the specific problem context and the general science concepts are a key aspect of helping students generalize their experiences.

This current study examines student work from the IQWST *What will Survive* unit (Bruozas et al., 2004). This eight-week unit is broken into two parts. In part 1, students are asked to construct plans to remove the sea lamprey, an invasive species, from the Great Lakes. In order to construct this plan, students investigate the concepts around the interconnectivity of food webs, the relationship between structure and function (e.g. the kind of beak a bird has affects the kind of food it can eat and hence, where it can live) and competition. In part 2, the students are asked to examine what causes populations to change over time, focusing on how some finches were able to differentially survive a drought. During this month, the students examine ideas around natural variation in traits and differential survival.

The *What will Survive* unit (Bruozas et al., 2004) focuses on the practice of constructing and defending explanations by introducing the practice, defining the three components and providing the students and teacher with eight opportunities to construct and discuss explanations. This study focuses on three of those opportunities that represent a range of types of scientific explanations:

- Lesson 6: in this lesson, students explore a computer simulation of a simplified food web of grass, rabbits and foxes constructed using NetLogo (Wilensky, 1999). Once they have become familiar with the interactions between these three organisms, students add an "unknown invader." The lesson concludes with pairs of students constructing a scientific explanation about where the invader fits in the food web, identifying the organism with which the invader competes for food. The evidence for this explanation comes from graphs of population fluctuations, created by the computer simulation.

- Lesson 7: in this lesson, students work with paper graphs, similar to those produced by the computer simulation in the previous lesson. These graphs depict population fluctuations in the Great Lakes, before and after the sea lamprey was introduced. Individual students use these graphs to construct a scientific explanation describing "the change in population of the chub, after the sea lamprey invaded." We envisioned that the students' evidence would be drawn from the food web image they had received (e.g. "the food web shows that the trout eats the chub"), and the graphs showing changes in the populations before and after the sea lamprey was introduced.
- Lesson 13: Lesson 13 includes a two-week project in which the students investigate the Galapagos Finches population database holding information about the finch population on the Galapagos Islands (Reiser et al., 2001; Tabak, 2004). Students are asked to work in pairs in order to interpret the computer data and determine why so many finches died during the dry season of 1977, and why some were able to survive. The scientifically supported explanations for this question use data to identify which trait variations enabled birds to differentially survive the drought. For example, one response could state that the birds that survived the drought had longer beaks, enabling them to crack the harder seeds that also survived the drought. Another plausible argument consistent with the data (but less accurate scientifically) could be that the birds that weighed more had fat stores, making them better able to survive the food shortage that resulted from the drought.

We selected these three lessons because they represent the range of evidence available and the types of claims that students construct throughout the unit. These lessons make available a number of different data sources: from the background information provided by food webs to population graphs to a collection of data that students must shift through in order to discover the most relevant pieces. Further, in these three questions we see two different types of claims: in lesson 6 are students asked to identify a competitor while in lessons 7 and 13 they construct a causal account describing why the phenomenon occurred. We expected that this diversity would create opportunities for students to use the instructional framework differently, thereby exposing us to broader uses of the framework.

## METHOD

### DATA COLLECTED

In this study, we examined three classes as they implemented the *What will Survive* curriculum. For each of these classes, we collected daily videotapes, pre/post tests, pre/post interviews of a subset of the students and all written artifacts. Through this data collection, the researchers maintained an observer stance, occasionally stepping into a participant role in order to conduct spontaneous interviews as students worked through the lessons, or to help the teacher respond to a student question.

For this paper, we examine the students' written explanations. These are typically 3–5 sentence paragraphs that respond to a prompt for an explanation. For example, in lesson 6 students are asked to construct an explanation "explaining which organism the invasive species competes with." The students write about half of these explanations individually, the other half are written in pairs or small groups. In the lessons on which we focus for this paper, the students write individual explanations in lesson 7 and work in pairs for lessons 6 and 13.

STUDY CONTEXT

The classes selected for this paper provide a diverse participant pool, thereby making it more likely that their responses would reflect a range of potential uses of the instructional framework. There are a total of a total of 53 students represented in this study: 16 from classroom one, 20 from classroom two, and 17 from classroom three (for a total of 28 females and 25 males).

Classroom 1: Classroom one was in a suburban middle school, outside of a large Midwestern city. While the curriculum supports the introduction of scientific explanations in lesson 3, this teacher (Teacher 1) introduced scientific explanations in a six-minute discussion, during lesson 5. She used this opportunity to identify the components claim, evidence and reasoning, in the instructional framework. The class defined and discussed the importance of each piece. In the middle of this discussion Ms M. reviewed these components:

> A claim is just a simple little statement. Evidence is just what it is, it is just evidence, it is just some numbers or something to support it. And the last part, the reasoning is where you take it a step further, and you say: 'ok, now that I've shown you that this is true here is the next logical step', so that is the hardest part to write (classroom observations, 01.14.04).

Classroom 2: Classroom two is in the same suburb as classroom one, but is in a K-8 magnet school. Teacher 2 introduced scientific explanations in lesson 3 by connecting them to lab reports with which the students were familiar. Using this analogy, the teacher associated the claim with the "conclusion," and the evidence with the "data summary." She informed the students that the reasoning didn't fit neatly into one of the sections of a lab report, but that the students had done it before. Teacher two defined reasoning as a statement of "why you think it worked that way" (classroom, observations, 03.02.04).

Classroom 3: Classroom three was in a grade 7–12 school in a large Midwestern city. This class started the *What will Survive* unit immediately after completing the IQWST chemistry unit *How Can I Make New Stuff from Old*. As a result, these students came into the unit with some familiarity with scientific explanations and the components in our instructional framework. Consequently, we do not have any data regarding how the teacher introduced these components. This class is also anomalous in that they started *What will Survive* towards the end of the school year and they only worked through part 1. This class will be doing the second half of this unit in April of 2005. In addition, this classroom was a pilot test of additional materials to integrate explicit classroom discussions around the nature of science. These discussions covered topics such as the importance of using empirical evidence and logical reasoning, the difference between observation and inference, and that science is based on interpretation (Kenyon & Reiser, 2005).

## ANALYSIS APPROACH

In this study, we attempt to characterize the ways in which students fulfill the three curricular goals of *sense making, articulating* and *defending* their understandings, as revealed through their written explanations. To do this, we engaged in an iterative, inductive analysis of a total of 92 written responses to three questions, looking for patterns in how the students fulfilled each of the components.

Throughout this, our coding scheme emerged out of the students' work. In the first pass through this data, we simply attempted to identify the three components of claim, evidence and reasoning, in each response. We quickly discovered that even this level of coding was difficult; we were often unable to tease apart these three components in a single response. This finding alerted us to the fact that the students were not making the elements of the framework explicit and drove us to understand whether and how the students were using the framework and how these different uses appeared to satisfy our three curricular goals. To that end, we began an iterative analysis of these "odd" cases attempting to determine ways of characterizing how these explanations differed from the expectation.

As described, our analysis focuses on how the instructional framework appears to influence students' fulfillment of the three curricular goals. Given this focus, we are not assessing the accuracy of the students' responses. We found that the scientific accuracy was not a challenge for students: all 92 responses in the data corpus correctly use the relevant science ideas (12 of those responses appear to have partial understandings). Further, as will be demonstrated in the first example below, it is often difficult to discretely identify each component of the instructional framework. Thus, we do not explicitly examine whether each of the three components are present in the students' work.

In the following sections, we begin by closely examining two explanations that represent the two general types of responses that students constructed. We then move on to identify the structural characteristics that were often present in these different types of responses and connect these specific examples to the more general data corpus of 92 responses. Throughout this analysis, we examine the students' use of language to understand how they applied the instructional framework and satisfied the curricular goals.

## EXAMPLE EXPLANATIONS

Both of our sample explanations come from students in class 1 as they address the culminating question in lesson 13. As mentioned above, throughout this investigation, students are tasked with discovering why some finches were able to survive a drought. The students then construct a scientific explanation about what happened. We selected responses from lesson 13 because it is the most complex explanation the students construct – it consequently resulted in the most interesting analyses. We chose these two specific responses because they reveal similar understandings of the phenomenon, but communicate it in strikingly different ways. We found these answers to be prototypical of the two different types of responses the students constructed.

The following example represents a typical response. Although this response is coherent and seems sound, the students are not making clear to readers which parts of their explanation are based directly on their 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[2] to the Tribulus and be able to eat the seeds without dying (Classroom 1, Student Group JH, Finch Survival)[3].

The students in this response have synthesized the available data in order to construct an explanation about why so many birds died and some survived. Throughout this explanation, the students reference the evidence they gathered (e.g. the Chamae, Portulaca and cactus were scarce and the Tribulus had harder seeds). Further, the implicit and explicit connections in this response express the students' reasoning (e.g. the plants not growing caused the birds to compete for the few seeds that remained). Thus, in some ways, they have accomplished the task – they have used evidence and reasoning to present a coherent explanation about the phenomenon under study. However, readers that were unfamiliar with the students' problem context and the available data would have a difficult time deciding whether they believed the students' claim. These unfamiliar readers would be unable to determine which ideas in the above explanation were new and which were already understood and accepted before the research. Further, of the new information, the readers would not know which pieces were the students' speculations and which were facts. Thus, while we (as a familiar audience) can 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.

The second example exemplifies a different approach to communicating the explanation. As with the students in the first example, these students claim that some birds survived because they ate a specific plant – the Tribulus. After explaining what happened, these students present 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 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).

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

[3] 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.

Unlike the first example response, these students appear to use the instructional framework provided in the unit to structure their explanation of the finch phenomenon. That is, it appears that the first sentence fulfills the claim component, the following three sentences provide evidence and the final three sentences are the students' reasoning. Thus, as a reader, it is easier to determine what information is new (the claim), which aspects of the response come from data (the evidence), and which are the students' inferences (the reasoning).

When considering the students' task, both of these responses makes sense; students were asked to construct a scientific explanation about why so many birds died, but some survived. Both student groups accomplished this: they both used evidence to explain the differential survival of some finches. However, the instructional framework is designed to do more than support the students in making sense of a phenomenon. It should structure the way that students communicate and defend their understandings, as well. These examples reveal different degrees of clarity in the students' responses, raising a number of questions. Is it important for students to follow the instructional framework? Are the students that do not explicitly state the claim, evidence and reasoning components achieving our pedagogical goals of *articulating* and *defending* their understanding? What are the necessary elements of these components? For example, does the evidence need to be carefully distinguished from the other components?

In order to understand the ways in which students construct and communicate their explanations, we attempted to identify patterns across the various student responses. Motivated by the contrasts in the two examples above, we examined the corpus to identify the general dimensions that characterized how students differed in their explanations, so that we can consider the obstacles they may have encountered that led to this variation in their practice. Through this process, we identified two general structural characteristics that can be used to characterize the differences in clarity in communicating explanations, as evidence in the above examples: 1) the degree to which the inferences and evidence are differentiated and 2) the use of persuasive statements. In the following sections we extend our analysis of these two example explanations to describe these characteristics, and exploring the representativeness of these contrasts through additional examples and numerical data from the entire corpus.

**DIFFERENTIATING BETWEEN INFERENCES AND EVIDENCE**

As described in the science education research literature, the distinction between inference and evidence is key throughout the inquiry process (e.g., Driver et al., 2000; Duschl, 2000). From a learning perspective, understanding this distinction enables students to identify which aspects of their explanations need additional support – which additional questions to pursue. From a communicative perspective, clearly differentiating between evidence and inference enables readers to scientifically evaluate the merit of the students' claims. The instructional framework attempts to support students in making this distinction by including the evidence component as an explicit and necessary element of explanations.

As defined, the evidence component should contain the facts that students gathered through observation, discussion, reading and experimentation that bears on the knowledge claims. When *making sense* of the phenomena under study, students are expected to use the facts to figure out what was happening; to determine the claim they want to make or to evaluate a competing claim. For example, in the finch problem that these students address, the students examine a range of data including field notes about finch behaviors, charts of seed counts and graphs showing the survival rates of birds with different characteristics. The students combine all of this data to construct their understandings of the finch phenomenon. When *articulating* their understandings, students use the evidence to *defend* these claims: to state the evidence that supports their claims. As demonstrated in the two examples, not all students explicitly fulfilled the evidence component.

The students in the first example have embedded their evidence with their suppositions. As a result of this rhetorical structure, 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 facts that are available in the computer database: "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. This raises questions such as how do the students know that the surviving birds ate Tribulus? Thus, these students have provided little guidance to support the reader in determining what is fact and what is inference thereby making it difficult for the reader to evaluate whether the claim is accurate and believable.

This structure also hides the evidence and inference distinction from other students in the same classroom. That is, this problem context is rich enough for students to pursue different paths through the data and to construct different interpretations of the complex data set. Thus, it is entirely probable that each student group will look at slightly different data sets, making them "unfamiliar readers" of each others' work. Thus, when discussing explanations such as the one in example 1, students may not be able to tell what data the authors are referencing (if any) when they write assertions that move ambiguously between evidence and inferences. This makes it difficult for the students to engage in a discourse in which they evaluate their claims in light of alternatives.

The problem of embedding evidence and inference was widespread in these written explanations. This embedding of evidence and inference happened in about 45% of the 92 responses we examined.

The majority of the second example provides clearly distinguished evidence and inferences. For example, the sentence "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." labels the data source thereby helping to identify the information as fact.

It is important to recognize the continuous nature of this dimension. For example, even the second response that contains clearly identifiable evidence and inferences also contains data that is embedded with the inferences (we have italicized the clauses that reference facts available to the students in the database): "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*." As shown by the italics, these students have embedded implicit references to data throughout their claim – much as the students in example 1 do.

Even with the continuous nature of the embedded/differentiated distinction, we found it to be an important and powerful way of characterizing the student responses. In cases such as the second example, we determined how to code it by examining the entire explanation. In this case, regardless of how we characterize the claim, the evidence and suppositions are differentiated throughout the rest of the response. In this example, we see the two structural characteristics that students most often used to differentiate between the evidence and inferences: they provide data that is close to its original form and they reference the evidence sources. In the following two sections we provide additional examples of how students present data and provide citations to communicate the distinction between their evidence and inferences.

REFERENCING EVIDENCE SOURCES

The most explicit way these students distinguish between factual information and supposition is to cite the data source. In the examples from above, the students explicitly reference their data sources two ways: 1) Naming the evidence source, such as "The charts of cactus, Portulaca, and Chamae all show…" 2) Generally referencing the evidence "The research of four birds that survived showed…" or "the graph shows that…"

In both of these citations, 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: when coding the responses, how precise of a citation are we looking for? In the first citation types, the students tell their reader that they are looking at charts and they identify the plants on the charts. Knowing the database with which the students are working enables teachers and researchers to identify exactly what chart the students are referencing in this sentence. However, in the second, more general, citation it is difficult to determine the details – which birds have the students examined? At what graph are the students looking?

While the precision of the citation is important for scientists, it is less so in this context in which the data available to the students is limited, making the source relatively obvious. Moreover, regardless of the specificity of a reference, the citation itself serves to differentiate between evidence and inference. Thus, as we examined the corpus of scientific explanations, we looked for clauses that clearly identified the information as evidence-based, regardless of the level of precision. Thus far, we have seen five general ways of accomplishing this, that vary in how precise they are in identifying evidence and in separating it from inferences:

1. *Identifying evidence sources* with statements such as "The charts…all show…" (from above). Note that this citation refers specifically to graphs that the students included with their prose. The clause "I looked on my food web and saw…" also fulfills this citation-type as it refers to a specific chart in the student's binder. This was the most explicit type of citation that the students provided.
2. *Referencing evidence, generally,* such as the example from above, in which the students reference their "research of four birds." This is an example of a more general reference because the students are alluding to field notes about birds, but have not identified which of the over 200 birds they are examining. The statement: "My evidence is that…" is an

additional example of this more general reference type. While these citations do not provide a lot of confidence regarding the evidence source, they communicate that the students are using data.

3. *Bounding their statements by referencing the time or context* in which their evidence occurred. This is a weak data reference, however we find that statements such as "When the invasive species was put into the environment…" communicate that the observation the student is referencing did occur. That is, in order to happen at a specific time or context, the event must have happened, and is therefore not an inference. It is key that this statement is in past tense; a future tense would indicate that the student was predicting what would happen, rather than describing what did occur.
4. *Attributing confidence in the information presented* with statements such as "I know this [the claim] because…" As with our third category, these statements of confidence are a weak reference to data. However, statements such as this were often used to rhetorically separate the facts from the inferences.
5. Similarly, some students differentiated between their inferences and evidence by *implying that the evidence is something they know*. Students do this by calling the inference out as something that is not fact using phrases such as: "I think" or "I believe." For example, examine the following response "…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" (Classroom 3, Student S, lesson 6) The first of these sentences provides unreferenced data, but the student has identified the second sentence as specifically containing an inference; it is what she *thinks* happened. Thus, while the student has not referenced her data source she has differentiated between the evidence and inference by highlighting the inference as something different from the evidence. This student is claiming confidence in her evidence by implying that it is something she knows, rather than something she thinks.

As seen, each of these characteristics offers different levels of specificity. For example, type 1, identifying the evidence source, enables the readers to find the graph and check the students' interpretations for themselves while the last types merely identify the clause as being fact-based. That said, regardless of their specificity, each of these different ways of referencing data sources help readers differentiate between the parts of the students' explanation that are evidence and those that are inferences. In the following section, we consider the second way in which students make clear the distinction between their evidence and inferences.

DATA PRESENTATION

Presenting data in a form that is similar to that of the original data source is the second way in which these students distinguish between their evidence and inferences. In the first example from above, the students report that most of the seeds are "very scarce" and that the Tribulus seeds are "harder and lengthier." In this response, the reader is not given an opportunity to determine that most of the plant seeds are "very scarce," instead the reader must trust the students' interpretation of the situation. Moreover, the structure of this sentence implies that the Tribulus seeds are 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 have stated data that is stated as though it were an inference virtually hiding the fact that the students were working with data at all. As seen, this presentation provides the audience with an incomplete understanding of the information available and makes the reader unable to distinguish between the pieces of the explanation that are factual and which are supposition.

The second example, on the other hand, provides a description of the data that is closer to the original, thereby allowing the readers to determine what the information means. 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. Thus, in this example, the reader has 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 the other structural characteristics we've identified, the data presentation 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 are working with a computer model of a simple ecosystem that contains foxes, rabbits, grass and an unknown invader. The students use graphs of the population fluctuations to determine which of the other organisms the unknown invader eats.

In response to this question, student EJ states:

> …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 refers 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 has made it difficult for the reader to recognize that he is even looking at the graphs or talking about population sizes. A reader that 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, differentiates her evidence by describing what is happening 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 the student describes changes in the population sizes. While this is an interpretation (she has not provided the raw numerical data), it is closer to the original data and allows the readers to construct a relatively clear picture of the relationships in her data set. Thus, explicitly describing the graph has 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 helps the reader understand the students' data and evaluate their claims. When evidence is presented in a from that seems unrelated to the original data source, such as the evidence seen in the first example from both the finch and ecosystem 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 is often indistinguishable from the students' inferences.

We found the two characteristics of referencing data sources and presenting data that is close to its original form to be prevalent throughout our data corpus. Table 1 presents the percentage of the 92 analyzed responses that reflect the various dimensions for each characteristic that students used to when constructing their explanations.

Table 1: Frequency of the characteristic dimensions

| | | | |
|---|---|---|---|
| Similarity Between Raw Data | Dissimilar: 42% | Medium: 6% | Highly Similar: 52% |

| | | | |
|---|---|---|---|
| and Data Presentation | | | |
| Referencing Evidence | No citations: 26% | | Cite data source: 74% |

Through our analysis, we used these dimensions to help determine whether the students were embedding their evidence within their inferences or whether the two elements were differentiated. It is important to note that while evidence citation and describing the raw data helped students distinguish between their evidence and inferences, these characteristics are only indicative; they are not diagnostic of the differentiation level. These characteristics are not diagnostic because they are continuous, rather than discrete, as is the level of differentiation. For example, if a student uses one of the weaker citation techniques listed above (e.g. time bounding a statement), they have not necessarily differentiated their evidence completely. Further, while related, these characteristics did not always go together. For example, a response may contain evidence that is presented in a form similar to that of the data source (thereby allowing the reader to interpret it), but not cite the source. Thus, the two characteristics 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 and 46% clearly differentiated them, while 9% of the responses were middle-ground cases.

## PERSUADING THE READER

In the reasoning component of explanations, students were expected to connect their claim to their evidence – telling the reader why their evidence supported their claim. While this component was intended to encourage students to state general scientific concepts, most of our students fulfilled the requirement by stating a narrative account that linked the evidence and the claim. For example, in the second response from above the students link their evidence regarding the Tribulus plant's survival to the survival of finches that ate it, saying:

> Which means that the drought didn't effect the tribulus plant, which didn't effect the ground finches that ate it….the Tribulus was the best surviving plant of the drought in '77, which didn't effect [sic] those who 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).

While this reasoning does not include a general principle, it does fulfill the instructional goal that students connect their evidence and claim.

Notice the penultimate sentence in the students' reasoning: "According to the information we found, our hypothesis is correct." We found that about 29% of the responses in our data corpus included statements such as this, in which the students are overtly attempting to persuade the reader. These statements are seen as part of the reasoning component because students use them to make obvious that they are basing their claims in evidence.

O'Neill (2001) calls these "overt persuasion" statements. Students typically provide overtly persuasive statements two ways:

1. *Asserting the accuracy of the claim*, by using phrases such as "this [the evidence above] proves…" or, as in the example from the finch responses, "…our hypothesis is correct…"
2. *Providing a counter argument* to strengthen the claim. For example, in the following example the student states her original hypothesis and then demonstrates why it is incorrect: "The invasive species is competing for grass with bunnys [sic]. At first my group thought that the invasive species was competing with foxes, for bunnys. After more generations and more research, when bunnys die out, the invasive species lives on [so it must not eat bunnies]…" (Classroom 2, Student EJ, lesson 6). While this example does not provide evidence supporting the claim, it does attempt to persuade the reader that the alternative is incorrect.

These persuasive statements are not a requirement of the instructional framework. Students often use them to help spell out their logic (e.g. "believe me because X follows Y"), but it is entirely possible to provide the three instructional framework components without using persuasive sentences. Nor are persuasive clauses necessary for the three curricular goals of *sense-making*, *articulating* and *defending*. We included this characteristic in our analysis because these clauses allowed students to say: "believe me for these reasons," That is, these "overtly persuasive" statements indicate that students were attending to the third goal of *defending* their understandings.

### EXAMPLE EXPLANATION SUMMARY

Table 2, presents the structural characteristics described above, summarizing our analysis of the examples with which we opened our investigation.

Table 2: Summary of the characteristics in each example explanation

| | Example 1 | Example 2 |
|---|---|---|
| Embedded vs. Differentiated Evidence | Evidence and inferences are embedded. | Evidence and inferences are differentiated. |
| 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"). |
| Referencing Data Sources | No references or citations | Names two different data sources. |
| Use of Persuasive Statements | No persuasive statements | States: "According to the information we found, our hypothesis is correct." |

Examining the entire data corpus demonstrates that this pattern of structural characteristics is not uncommon. Clearly, we define evidence differentiation in terms of data presentation and the presence of citations, thus these categories are dependent and have an uninteresting relationship. However, there is no definitional relationship between differentiating the evidence and using persuasive statements – persuasive sentences are not seen as one of the ways to differentiate evidence and inferences. Even so, as table 3 shows, students were much more likely to include these persuasive statements in responses that differentiated between the evidence and inferences than those that embedded them.

Table 3: Relationship between differentiation and persuasive statements

| | **No Persuasive Statements** | **Contains Persuasive Statements** | **Totals** |
|---|---|---|---|
| **Embedded Evidence and Inferences** | 35 | 7 | 42 |
| **Partly Differentiated Evidence** | 6 | 3 | 9 |
| **Differentiated Evidence** | 24 | 17 | 41 |
| **Totals** | 65 | 27 | 92 |

This table tells us that 41% of the responses that differentiate between the evidence and inference contain persuasive statements while only 17% of the responses with embedded evidence and inference contain them. This results in a significant relationship (chi-squared test result of $p < 0.05$) between the two characteristics: students are more likely to use persuasive statements if they differentiate between their evidence and inferences.

## DISCUSSION

We began this paper with the general goal of supporting learners in the process of constructing and defending scientific explanations. Our review of the literature on scientific explanation and the related idea of scientific argument identified three curricular goals that comprise the related aspects of this practice: 1) engaging in *sense making* to construct an explanation; 2) *articulating* one's understanding as a explanation, to communicate this understanding to others; and 3) convincing others of the explanation by *defending* it with scientific evidence and principles. This third goal of *defending* an explanation both makes explicit the epistemic commitments of the science and can be seen as a motivator for student engagement.

In attempting to support this multi-faceted practice for learners through an instructional framework, the IQWST design team distilled these ideas into the critical elements of claim, evidence, and reasoning. In this study, we examined the utility of this framework, investigating which of the three goals the framework manages to capture and communicate to students, and ways that the framework may need to be elaborated.

Our analyses focused on two prototypical student explanations. Through this analysis we identified two general structural characteristics that seemed to characterize the differences between these responses: 1) the level of differentiation between evidence and inferences and 2) the use of overtly persuasive clauses. Both of these characteristics relate to the third curricular goal that students *defend* their understandings. When discussing these two characteristics, it is important to note their different levels of instructional value: students should explicitly differentiate between their evidence and inferences, but the persuasive statements are not a requirement. While not required, the persuasive statements are important because they overtly attend to the third goal of *defending* an understanding. In these clauses the students are saying: "let me tell you why you should believe me." Therefore, these clauses make it apparent that the students are attending to this third goal. Explicitly differentiating between the evidence and inference also addresses this third goal of defense by supporting the unfamiliar readers as they evaluate whether the claim is believable.

When considering these examples in light of the three curricular goals, it appears that both responses fulfill the first two goals. That is, both responses *articulate* a coherent, cohesive understanding of why some finches were able to survive the drought. Further, these understandings are connected to the available evidence and science ideas. Clearly, in order to *articulate* this understanding the students had to construct it first, thereby accomplishing our first goal that students engage in *sense making* by using the available data to explain the phenomenon to themselves. Thus, it appears that, as previous research found, highlighting the components of claim, evidence and reasoning helps the students ground their explanations in evidence and scientific ideas (McNeill et al., 2003; McNeill & Krajcik, in press).

However, we argue that while the students that wrote example 1 fulfilled the first two goals, they did not satisfy the final goal of *defending* their newfound understanding. As seen through the analysis, example 1 neither supports an unfamiliar reader in distinguishing between the students' evidence and inferences nor attempts to overtly convince the reader of their claim. Without making the distinction between evidence and inference explicit, these students have made it difficult for readers to judge the strength of their evidence. In addition, this weaving together of the evidence and inferences makes it difficult for the authors themselves to evaluate their claims in light of alternative theories. Thus, while the students may actually have been clear in the conversations within their own group, their written products share the confusions that many learners exhibit of failing to distinguish their treatment of knowledge claims from the evidence that can support or refute them (Kuhn, D., Amsel, & O'Loughlin, 1988).

The students that produced example 2, on the other hand, have done both of these things: they have clearly supported the evaluation of their claim by identifying what is fact and what is supposition and by asserting the accuracy of their claim. Thus, example 2 attends to the third goal of using evidence and scientific concepts to *defend* a claim. Given the prevalence of examples such as those represented by example 1, it appears that the IQWST instructional framework as enacted, was not completely effective in helping students accomplish our third goal of *defending* their understandings.

This analysis reveals a critical way in which some learners' engagement in this practice can depart from the target practice: they are not consistently attending to the goal of convincing others. That is, the challenges that students face – their lack of differentiation between evidence and inference – suggests that while students seemed to use evidence to constrain the explanations they constructed, they were less careful in articulating and defending that understanding.

This inattention to audience is consistent with the general challenge of bringing inquiry science into classrooms. Establishing the authenticity of the knowledge building activity is one difficulty in creating an inquiry community in classrooms (Cornelius & Herrenkohl, 2004; Engle & Conant, 2002; Jimenenez-Aleixandre et al., 2000; Kelly & Chen, 1999; Scardamalia & Bereiter, 1994; Tabak & Baumgartner, 2004; Tzou & Reiser, 2004). For example, questions are typically prescribed by teachers rather than emerging from students' interests (Cazden, 1988; Mehan, 1979). As a consequence, the audience for what one learns is typically thought to be the teacher, who is interested in checking that students have learned, rather than a scientific community that is genuinely interested in answers to a scientific puzzle. Yet the sense of scientific explanation that the IQWST team is trying to inculcate requires that students consider how an audience would understand the explanation: where claims require a chain of reasoning to be plausible and where the claims and inferences require empirical evidence and connection to scientific principles to be convincing.

Thus, while the generic prompts provided by the instructional framework have helped cue students that they must incorporate evidence into their *sense making* process, they are not clearly helping the students to articulate the relationship between their evidence and inferences. Given that understanding this relationship between evidence and claims is the lynch pin of understanding how scientific knowledge is constructed – of understanding the nature of science – future iterations of our instructional framework will work to emphasize the goal that students engage in persuasive discourse by defending their explanations.

**Design Implications**

This finding leads us to ask: how can the IQWST designs more fully support students in attending to the epistemic categories of evidence and inference when communicating their explanations. How can curriculum facilitate the students in *defending* their explanations?

As currently written, the *What will Survive* unit appears to under-specify the goal of defending one's claim. That is, students are given the framework and asked to use it while "constructing a scientific explanation," but the persuasive goal for their writing is not highlighted. This occurs because the IQWST framework focuses on the cognitive elements of the practice of constructing and defending scientific explanations. That is, the framework identifies the components that a good scientific explanation must contain and the types of reasoning in which students should engage when constructing explanations. Given the challenges students faced with the third goal of *defending* their explanations, it may be fruitful to examine the social interactions that support the types of knowledge building in which we wish students to engage (Tzou & Reiser, 2004). We hypothesize that engaging in the *defense* of an explanation requires that students have an audience – that there is a need for the students to defend their explanations.

Creating an authentic audience may require that classroom activity structures drastically change – that the teacher no longer be the sole authority on knowledge and that collaboration and consensus become key elements of the student-to-student interactions. That is, part of what makes the practice of constructing and defending explanations sensible may be the act of consensus building, in which scientists engage but in which students rarely have opportunities to participate. This type of interaction requires a social context in which students expect to learn from one another's explanations (Hogan & Corey, 2001) and a problem context in which competing explanations are possible (de Vries et al., 2002). The problem context for the finch explanations, on which we focused, is rich enough to satisfy this second goal. However, the curriculum does not support the teachers in establishing this social expectation that students share and learn from each other.

When examining the existing supports, we found two related potential changes that could influence the ways in which students engage with this practice: 1) the components could be motivated in terms of how they help to *persuade* the audience and 2) the students could be given explicit criteria for choosing between explanations or selecting appropriate evidence. First, our existing pedagogical supports identify the types of things that a scientific explanation should contain and facilitates the teacher and students in constructing an understanding of each of these components. However, this framework has not helped the students to understand why each of these components is necessary. We anticipate that highlighting the persuasive purpose of each component would both help to emphasize the necessity of *defending* a claim and begin to make the apparent the relationships between these different components.

Second, while our existing supports define the components, they do not provide the students with criteria to choose between potential ways of fulfilling the components (for example, to choose between competing claims or to select evidence from the available data). Without this information, students do not have the information necessary to use the epistemic commitments of the scientific community to construct a defense of their ideas. Providing this information would be a step towards empowering students to engage in persuasive discourse about their ideas.

## NEXT STEPS

Given the potential problems with the existing design, we are exploring three strategies for helping to motivate the components and to make the criteria more explicit to the students: 1) empower students to be each other's audience 2) refine the instructional framework and 3) use elements from the nature of science literature to explicate the criteria for each component.

### EMPOWER STUDENTS TO BE EACH OTHER'S AUDIENCE

In order to make the need that students *defend* their understandings authentic, we must create a context and a culture that evokes an audience for the students' explanations. Without this, we find that the *defense* of an explanation is an inauthentic experience that results in students "doing school" (Jimenenez-Aleixandre et al., 2000) rather than engaging with the process of explaining the phenomenon. We are currently focusing on student debate and discussion to evoke this audience. That is, we are designing supports to enable the students become one another's audience. This strategy helps to make the classroom interactions more like those of scientists in which knowledge is constructed through a social process of theory development and revision (Carey & Smith, 1993; Driver et al., 2000).

### REFINE THE INSTRUCTIONAL FRAMEWORK

In order to motivate each component of the framework (claim, evidence and reasoning) we attempted to elaborate the existing framework. In this refinement, we added prompting questions to each element of the instructional framework. We designed these questions to make the purpose of each component apparent. These questions play the role of scaffolding prompts, extending the definition of the components to remind learners not only what explanations need to contain, but what each of these constituents needs to accomplish. These prompts are designed to scaffold learners, similar to the instructional software prompts that remind learners how to break down complex activities into component steps (Davis, 2003; Fretz et al., 2002; Quintana et al., 2004). The three explanation component / prompting question pairs are:

1. *What is the answer?* (This question aligns with the existing claim component.) To address this question, students will respond to the prompt in their student books. Thus, students will make a claim about what they think happened, why it happened, how it happened, etc. For example, if asked why the rabbits decreased when an invader entered the ecosystem a student may claim, "the invader eats the grass, the rabbits food."

2. *Why does that make sense scientifically?* (This question aligns with the existing 'reasoning' component.) To address this question, students must identify things that they know about the world that make their claim believable, and how their evidence connects, logically, to their claim. Continuing the example from above, the student may say: "We know that when two species compete for food, an increase in one species can cause a decrease in its competitors."
3. *How do you know you're right?* (This question aligns with the evidence component of the instructional framework.) In order to respond to this question, students will supply the evidence they used when either constructing or testing their claim. For example, the student from above may say: "Sure— just look at these graphs. Graph 1 shows a decrease in rabbits and an increase in invaders."

Using questions such as these, we intend to motivate the rhetorical importance of each component. Moreover, these questions will provide students with suggestions as to what they should ask themselves and one another as they construct, discuss and debate their ideas. Thus, not only do these questions make explicit that we want students to think about persuading one another, but they also provide students with a basic toolkit for doing so. These prompts articulate the basic types of information that an explanation should contain in order for it to be convincing.

### USE NATURE OF SCIENCE TO EXPLICATE CRITERIA

In our redesign, fostering a sense of audience requires that students are held accountable to one another for their claims. Thus, we must do more than highlight the types of information that a convincing explanation must contain; we must support the students in learning how to choose between their explanations, critique one another and revise their explanations. To that end, our final strategy is to unpack each of the three components, making the success criteria of each more apparent.

We are using the nature of science understandings about what makes good evidence and how science knowledge is constructed to identify these criteria. Specifically, we are focused on the ideas of: specificity of a claim, empirical evidence, reliability, validity and the tentative and subjective nature of science (Abd-El-Khalick & Lederman, 2000; McComas, Clough & Almazroa, 1988). These ideas are used to deconstruct the above questions that a convincing explanation must answer. For example, a claim must be specific enough to answer the question and the evidence must come from an empirical source (rather than the students' opinion or hearsay).

Using these three strategies, combined with an increased focus on student-to-student discussion around their ideas, we intend to make the third goal of *defending* explanations more apparent to students. To that end, we are currently engaged in redesigning *What will Survive* and pilot-testing these new strategies. We will analyze these results to examine three related questions:

1. Do these redesign strategies succeed in supporting the students as they work on the three aspects of explaining including *sense making, communicating* and *defending*?
2. Does the act of *defending* an explanation help students distinguish between the epistemological categories of evidence and inference?
3. And finally, does the act of *defending* an explanation foster deeper engagement in the classroom activities?

In this study we have examined students' written explanations in order to uncover the challenges they face when making sense of scientific phenomenon and articulating and defending those understandings. Through this analysis, we have seen students present coherent, evidence-based explanations. However, about half of these responses fail to distinguish between the evidence and inferences that were used to justify the claims. These responses reveal students struggling to effectively defend their growing understandings. We contend that attending to the audience for the explanations would help students focus on the defense their explanations, thereby motivating their attention to the differences between evidence and inferences as well as the engaging the students in the scientific discourse of sense making through persuasion and discussion.

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