STRUCTURING ACTIVITIES TO FOSTER ARGUMENTATIVE DISCOURSE

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Abstract

Scientific argumentation is seen as an increasingly important aspect of science education. However, engaging in argumentative discourse requires that students and teachers take on new roles and develop epistemic criteria that are more consistent with that of the scientific community. Thus, engaging in scientific argumentation requires transforming traditional classroom norms. In this paper we argue for a practice-based approach to supporting teachers and students in which we examine the ways in which the existing classroom norms support and inhibit student participation in scientific argumentation. Using this lens we see that we must "create a need" in the classroom environment for students to produce coherent, scientific arguments. To that end, we developed three design strategies to create this need for students and teachers to transform their classroom norms in order to engage in scientific argumentation. We conclude with preliminary data of a class that is utilizing our design strategies in which the students are engaging in scientific argumentation.

Introduction

Student engagement in scientific argumentation is increasingly seen as a key aspect of science education. First, by framing a conversation as persuasive, listeners are given more ownership – they have the opportunity and the responsibility to determine whether they agree with the speaker's claims (Tabak, 2002). In the more authoritative discourse found in typical classroom interactions, on the other hand, students must "acquire" the knowledge being provided – they have no opportunity to question the new information as they fit it into their existing understandings. Secondly, as speakers in persuasive discourse, students have the opportunity and the responsibility to defend their claims – to explain why their understandings make sense and should be believed. This articulation creates an opportunity for students to make their understandings external, thereby making it possible for them to compare and revise (Coleman, 1998). In both of these ways, scientific argumentation becomes a context in which students must reason about the scientific mechanism, actively constructing their own understandings. Finally, engaging in scientific argumentation enables students to experience scientific discourse practices, thereby motivating central beliefs and values of the scientific community, such as the importance of evidence (de Vries, Lund, & Michael, 2002; Driver, Newton, & Osborne, 2000; Duschl, 2000; Osborne, Erduran, & Simon, 2004; Sandoval & Reiser, 2004).

In this paper, we examine scientific argumentation as a practice in which students engage. We begin by combining literature examining argumentation and ways to foster it with our own analyses of student engagement in argumentation. Through this analysis, we see two aspects of argumentation that challenge students: epistemological and social. These aspects pose related challenges for students. This leads us to present a practice-based perspective on argumentation. Through this lens, we examine the ways in which the classroom norms inhibit and support students, as they engage in various aspects of scientific argumentation. We then propose design strategies for supporting students and teachers as they take on new norms that are more consistent with the practice of scientific argumentation. We conclude by illustrating a practice-based design approach to fostering scientific argumentation, using an example from our pilot studies.

Why is Scientific Argumentation Hard?

Scientific argumentation requires that students and teachers take on new and different roles in the classroom. As will be shown, typical classroom practices often inhibit student participation in this practice. In addition, many students hold scientific epistemologies that may affect how they engage in scientific argumentation. In the following two sections, we begin by discussing the epistemological challenges associated with scientific argumentation and then move on to the social ones. We finally examine the relationships between these two aspects of the practice and how these relationships influences our approach to supporting students as they engage in scientific argumentation.

EPISTEMOLOGICAL CHALLENGES

Much research has focused on students' epistemologies about science and how these beliefs can be revised through instruction and classroom activities (Lederman, 1992; Linn, Bell, & Hsi, 1998; Sandoval, 2005; Songer & Linn, 1991). This literature examines the students' beliefs about the types of knowledge that is valued as scientific, the types of questions that are worth investigating and the ways to investigate and answer these questions. It is based on the assumption that an individual's beliefs about science will influence how they engage in learning activities (Duschl, 2000). For example, students often view scientific knowledge as a set of stable and isolated facts that the they must memorize (Carey & Smith, 1993; Songer & Linn, 1991). In this view, students have no reason to engage with the ideas of their classmates; if students see science as a set of isolated, stable facts than their learning goal is to memorize the facts of the scientific world, rather than to make sense of that world. Thus, one challenge facing students, as they engage in scientific argumentation is to develop a more sophisticated epistemology in which scientific knowledge is seen as the a dynamic process of observations and iterative refinement.

In addition to understanding the dynamic process for constructing scientific knowledge, students are faced with learning new criteria for constructing and evaluating this knowledge. That is, constructing a knowledge claim in a way that is consistent with scientific inquiry requires that students connect the 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, Rodriguez, & Duschl, 2000). D. Kuhn (1989) and others have found that students often struggle with this – they typically do not differentiate between evidence and inference. Consequently, students do not reliably base their knowledge claims on the available evidence. If students do not use the epistemological criteria of science – a reliance on evidence – they are likely to reaffirm their misconceptions (e.g. D. Kuhn, 1989). Thus, if we want students to engage in productive scientific argumentation, they must learn to value the available evidence, using it as the primary criterion when evaluating one another's knowledge claims.

Over the last two years we have engaged in ongoing design research to understand the challenges students face as they engage in scientific argumentation. We are currently engaging in a study to examine the design strategies that are presented in this paper. Pre-interviews with these students help illustrate the epistemological challenges that we hope to address in our work. These interviews were designed to assess the student perceptions of argumentation in their science classrooms. The students discussed here are members of a class in which the teacher encourages students to use evidence to make sense of their experiences. We use these interviews here to illustrate the ways that student epistemologies about science are evident in their discussion and how these epistemologies are intertwined with classroom norms.

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

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

In this response, it appears that Student J does not attend to evidence in her arguments in science class. Instead, she apparently asks her teacher, the authority figure, to resolve disputes with her classmates. Student K refers to a similar method:

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

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

Thus, in both of these interview snippets, we see the students focusing on their teacher to resolve disputes, rather than the available evidence. This is an example of an epistemological challenge for engaging in argumentation: the students are using a different set of criteria to resolve their disputes than scientists do[1]. Moreover, Student K's interview reveals that students must also learn how to evaluate evidence. Thus, in order to

[1] We are currently engaging in classroom observations to determine whether these students' self-report align with their actions, in classroom activities.

make their arguments scientific, they would need to develop new epistemological criteria, emphasizing evidence as a deciding factor.

How do we design curricula with the goal of affecting the students' epistemologies about scientific knowledge? How can we help students believe that scientific knowledge is a malleable system of ideas that are constantly under revision? How can we influence students to rely on evidence as they construct these ideas? Much work has been done explicitly discussing these beliefs and providing students with historical examples that demonstrate the point (e.g. Lederman, 1992). Research in this vein presents evidence of the students' explicit epistemologies about science changing and concludes by emphasizing the importance of learning experiences that make the epistemological aspects of scientific inquiry explicit (Duschl, 2000). However, we still see little evidence that this explicit focus influences student engagement in practices, such as scientific argumentation (Kenyon & Reiser, 2005; Sandoval, 2005). Thus, we contend that we must go beyond telling students about the epistemic beliefs that more closely align with the scientific community; we must put them in social situations in which these beliefs make sense.

That is, in order for students to engage with the epistemological aspects of scientific argumentation, we need to think about the broader context in which they are used. For example, the belief that scientific knowledge is a set of isolated facts to be memorized is supported by traditional classroom norms in which the students' goal is to acquire the knowledge held by the teacher and textbooks. Moreover, this goal structure may explain the results of the above interview: if the students' ultimate goal is to acquire their teacher's knowledge than it is sensible for them to turn to her, instead of the evidence, when resolving disputes. Thus, more than telling students that scientific knowledge is a dynamic process of evaluating knowledge claims against the available evidence, students must be in situations in which this process is a logical approach to achieving their goals. Students must have opportunities to engage with the social aspects of argumentation.

SOCIAL CHALLENGES

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

For example, as discussed above, if the students' goal is to acquire the teacher's knowledge, students have no need or motivation to make sense of their own data. Moreover, in this situation, students have no need or motivation to engage with the social dimensions of argumentation; they have no reason to substantively engage with their classmates' understandings. Why should a student argue with his peer when the teacher knows the *right* answer? Moreover, common classroom interactions in which the teacher asks a question, a student answers and the teacher responds to the answer given (IRE)

(Lemke, 1990; Mehan, 1979) largely prevents students from engaging in student-to-student discussion (Hatano & Inagaki, 1991; Lemke, 1990). This interaction style neither enables nor necessitates that students build upon one another's contributions. Furthermore, even when working in small groups, students often fail to engage in productive argumentation and instead, look to the most "capable member" for the desired answer (Hatano & Inagaki, 1991). Thus, in typical classroom interactions, students have little opportunity or motivation to understand the substance of one another's ideas, nor consider whether they understand and agree with them.

These challenges with attending to the social dimensions of argumentation are apparent in how students engage in the practice. For example, in earlier work (L. Kuhn & Reiser, 2005), we present an analysis of students' written work that reveals students struggling to engage in the social dimensions of argumentation. In this paper, we contend that scientific argumentation entails two distinguishable goals: 1) using the available data to construct an understanding and 2) using the data as evidence to defend their understanding. We found that while the students in this study succeeded with the first goal thereby demonstrating ability to take on some of epistemic aspects of scientific argumentation, only about half of the responses addressed the second goal. We claim that by failing to defend their explanations with evidence, the students were not obviously attempting to convince their audience of the accuracy of their claim. That is, by not defending their understandings, the students were not attending to the social aspects of scientific argumentation.

In the following, we present two examples of student work on their final project. We use these to illustrate the ways in which students do and do not engage with the social aspects of argumentation, in their written work. These examples came from the culmination of a two-week project in which the students investigated a computer database containing information about the population of finches, on the Galapagos Islands (Reiser et al., 2001; Tabak, Smith, Sandoval, & Agganis, 1996). Students were asked to work in pairs in order to interpret the computer data and determine why a majority of the finches died during the dry season of 1977, and why some were able to survive. In order to answer this question, the students had to use data to identify trait variations that enabled birds to differentially survive the drought. This complex data set supports multiple plausible interpretations. For example, one response could state that the birds that survived the drought had longer beaks, enabling them to crack the harder seeds that also survived the drought. Another plausible argument 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.

In the following example, the students present a coherent account that is based in the available data. However, this explanation does not argue for the claim; rather than defending the claim by explicitly stating the evidence, evidence is buried in the narrative account of what happened. That is, the evidence in this explanation is indistinguishable from the students' claims.

> The rainfall decreased a lot which created the plants to not grow as much, so the Chamae, Portulaca, and Cactus had softer seeds so birds fought in competition for

> those plants. Since those plants were very scarce there was one other plant called the Tribulus, which had harder and lengthier seeds so the best chance for survival was to adapt[2] to the Tribulus and be able to eat the seeds without dying (Classroom 1, Student Group JH, Finch Survival)[3].

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

Student authors of explanations such as the above are not explicitly using evidence to construct an argument. They could be doing this for a number of reasons. First, they may not know what evidence is. We conclude that the fact that their explanation is constrained by the data – they are attending to it – implies that they know that data is an important aspect of scientific inquiry. Thus, we conclude that there is something else going on here.

It is possible that these students were not thinking about their audience at all; they may have simply been writing a paragraph. Alternatively, these students could have been writing for their teacher. In this interpretation, the students were writing for an audience that was familiar with the data and knew the right answer. When written this way, it appears that the students' explanations are demonstrating the solution to the mystery without attempting to convince the reader of the scientific accuracy of that claim. Regardless of the reasoning behind their structure, it appears that the students have not fully engaged with social aspects of scientific argumentation: they have not used evidence to convince their reader of the accuracy of their explanation[4].

In this second example, it appears that the students are more engaged with the social goals of argumentation; the structure of their writing allows readers to determine whether they are convinced that the students' explanation accounts for the available data. As with the students in the first example, these students claim that some birds survived because they ate a specific plant – the Tribulus. However, after explaining what happened, these students go on to present the supportive evidence and reasoning:

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[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 J and H 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 written.

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

> 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).

As with the first explanation, the authors of this second example have used evidence to construct a plausible account of the finch mystery. However, the difference in presentation implies that the students are attending to the social aspects of argumentation; by explicitly presenting their evidence, these students have enabled their audience to determine whether the evidence supports the claim. In this way, the students have attended to the social aspects of argumentation. Rather than writing to a teacher that knows the answer, these students seem to be persuading their audience that their explanation is correct.

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

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

ADDRESSING THESE CHALLENGES BY COMBINING THEM

The epistemic and social aspects of argumentation are clearly intricately connected. As discussed, the underlying rules of the classroom heavily influence the students' epistemologies about scientific knowledge (Smith, Maclin, Houghton, & G., 2000). Further, while our analysis of the students' written explanation focuses on whether they attended to the social goals of argumentation, an alternative interpretation is that the authors of the first explanation were using a different set of epistemological criteria to convince their readers of their explanation (the authors of the first explanation could have been relying on logic and plausibility to convince their audience whereas the authors of the second argument could have been relying on logic, plausibility and evidence). In this interpretation, the challenges that emerge in the writing could be attributed to epistemological, rather than social challenges.

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

How do we do this? How do we attend to the epistemic and social aspects of scientific argumentation? The following example taken from recent classroom pre-observations illustrates the complexity of this approach. In this classroom, the teacher designed an activity that attended to both the epistemic and social aspects of argumentation[5]. She asked her students to research different atoms and to prepare a presentation that would convince their classmates to "buy" their atom. On the day of the presentations, this teacher provided her students with a rubric to help them evaluate whether they would "buy" one another's atoms (see Figure 1). She also explicitly required her students to critique one another, calling on them to do so, between each presentation.

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

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

Table 1: Rubric Excerpt

Unfortunately, the students did not engage in the argumentative aspects of this task. First, few of the presentations addressed the goal of "selling" an atom; instead students generally provided factual PowerPoint presentations, focusing on the number of neutrons, protons and electrons, in their respective elements. When called on to critique the presenters, students often had nothing to say. Moreover, when they did comment, their evaluations were focused on surface elements of the presentation and were directed at the teacher rather than the student presenting. The teacher then evaluated each critique offered by a student, evaluating whether the student had responded to appropriate elements of the presentation. This focus allowed the presenters to ignore the feedback. In this way, the critiques appeared to be an opportunity for students in the audience to demonstrate that they were listening, rather than an opportunity for the author to improve.

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

We find that the challenges evident in this classroom reveal the paradigm shift we must make when attempting to foster student participation in scientific argumentation: we must do more than telling students it is time to argue (or, in this case, time to critique one another's presentations). We must think of scientific argumentation as a *practice*. Building on work in the situated cognition field (Cole, 1999; Lave & Wenger, 1991; Wertsch, 1991), we see that practices hold the community together – they stem from a common set of beliefs and values and are perpetuated by social norms. A practice-based perspective on scientific argumentation suggests that we examine the norms of the classroom, understanding the ways in which the typical behaviors, values and discourse of the classroom support and discourage student participation in scientific argumentation (building off work such as: Cobb, 2002; Duschl, 2000; Hatano & Inagaki, 1991; Herrenkohl et al., 1999; Hogan & Corey, 2001; Osborne et al., 2004).

Using the lens of *practice* to understand argumentation in classrooms, we see why simply telling the students to argue is an ineffective method for fostering argumentation. Telling students to argue does not address the ways in which this new practice – scientific argumentation – aligns with and differs from the existing classroom norms. In the example from above, we see that while the students were required to critique one another, the social norms of the classroom had not changed. That is, the students were still offering their feedback to their teacher, rather than the presenters being critiqued. In order to motivate students to move beyond this more typical paradigm we must change the classroom norms, creating situations in which engaging with one another is useful for their individual success. Thus, we see that fostering argumentation entails more than telling students to talk to one another; we must foster new expectations for how the students and teachers will interact. To that end, we must address the underlying goals and values in the classroom; students must find it valuable to attend to one another's ideas and evidence.

Further, when considering the criteria that students use when critiquing one another, we see that there must be alignment between the criteria and the ultimate goal. In the above vignette, the students were asked to determine whether they would buy an atom. This goal does not require that the students attend to one another's evidence. Instead, this goal focuses them on the superficial elements: was the presentation exciting enough to draw me in and stick with me? Do I think the atom is exciting? Given the alignment between the students' evaluative criteria and the questions they are answering, we must identify the kinds of questions that will motivate students to attend to one another's evidence. That is, we must take care to address the social aspects of argumentation in ways that are consistent with the epistemological aspects.

As described, fostering scientific argumentation requires more than telling students to argue. Moreover, the above examples demonstrate that the challenges students face when engaging in scientific argumentation go beyond learning the skills of using evidence or critiquing one another. We contend that in order to address the social and epistemological challenges to argumentation we must transform the norms of the classroom. That is, students must be in situations in which one another's ideas and the evidence supporting them are meaningful and important. Our design work focuses on this challenge: How do we create a need for students to take on new practices? In the following sections we present proposed design strategies for addressing this goal and an example from a classroom that utilized these strategies.

Design Strategies for Fostering Scientific Argumentation

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

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

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

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

Thus, when we use the phrase "create a need," we are referring to designing activities such that the goal of the activity intrinsically necessitates the new practice. This means that we need to look at the questions that are asked, the process through which students go to answer the questions, the criteria they use to evaluate answers and the way the teacher evaluates them. We need each of these aspects of the classroom activities to align with the new practice (in this case, scientific argumentation) such that the students experience why the norms of the new practice are useful and important. We see this alignment between the new practice and the classroom activities as the crux of our design strategy. Without this alignment, we see enactments such as the above example in which students transform the new practice to fit the existing classroom norms, instead of vice versa. The following descriptions of our design strategies make this idea more concrete as we describe ways to create a need for various aspects of scientific argumentation.

CREATE A NEED FOR STUDENTS TO USE EVIDENCE

As pointed out by DeVries, Lund and Baker (2002), in order for students to debate, the context must be rich enough to enable multiple perspectives. In future work we hope to explore this idea of "rich enough" – what makes a question rich? However, our current hypothesis is that the students need an opportunity to apply the evidence they are gathering. This application of the data makes the information necessary.

We see examples of problems that require students to make sense of evidence in much of the literature about scientific argumentation. For example, Blumenfeld (1991) talks about students designing artifacts that require students to use complex thought to integrate multiple pieces of information. Hatano and Inagaki's (1991) design approach begins with a question that has multiple possible answers. In the work by both Hatano and Inagaki (1991) and Osborne, Erduran and Simon (2004) we see the researchers presenting students with differing claims in which each claim is plausible, depending on your interpretation of the evidence. In each of these examples, researcher/designers create situations in which the students have a need to use data; the students are going beyond stating the data in order to apply it as evidence to solve the problem.

In the vignette above, the students were presenting facts (or data) about their atoms but the data was not in support of a claim. The question they were asked did not require that the facts be applied to solve a larger problem. Beyond affecting the presentations themselves, this narrow question focus also affected the audience members and their feedback. When determining whether to buy something, the surface features of the advertisement often distract individuals, as they evaluate the item. We believe that a similar phenomenon occurred here: the students were evaluating surface features of the presentation instead of the evidence because evidence was not necessary for them to engage with the question of whether they would "buy" the atom.

We wonder how this interaction would have changed if the question were tweaked such that the presenters were asked to describe what would happen if their element were no longer available. This framing of the question may have created a context in which the facts about the atom – the food it is in and the function it serves for humans – would have been necessary to construct and defend claims.

CREATE A NEED FOR STUDENTS TO ARGUE

The practice-based perspective on scientific argumentation tells that we need to go beyond asking the right questions. That is, while a rich question may create a need for students to use data when constructing their claims, it does not create a need for students to engage in the social aspects of argumentation; it does not create a need for them to engage with one another's ideas. To do this, students must be accountable to more than just the teacher; they must be accountable to each other as well (Brown & Campione, 1996; Engle & Conant, 2002).

This design strategy goes beyond the typical classroom activity of asking students to critique or discuss one another's ideas, as the teacher in the above vignette does when she requires students to critique one another's presentations. Unfortunately, the results seen in this class are also typical: students offer surface level criticisms without substantively engaging with one another's ideas. We have to find a way that this student-to-student discussion is a natural part of their learning process. The peer discussion needs to have a value for the student such that attending to one another's ideas becomes valuable to the students. We need to design situations such that students are motivated and empowered to engage with one another's ideas. In our design work we are attempting to design activities that accomplish this. We have currently created two such activity structures:

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

These two activities work together in that the second, the Whole Class Debate, provides a forum for the product of the first, the Argument Jigsaw. Thus, during the Argument Jigsaw students are aware that the product of their work will be presented to and questioned by their classmates. In this way, the Whole Class Debate is designed to *create a need* for the product of the Argument Jigsaw. It is important to note that, as a stand-alone activity, the Whole Class Debate is largely equivalent to the activity structure described in the above example. Thus, we clearly believe that the activity structure seen in the vignette has potential. Our hope is that pairing the Whole Class Debate with the Argument Jigsaw in order to address richer questions will help create a context in which this activity is more meaningful and engaging for the students.

MAKE THE EPISTEMIC CRITERIA EXPLICIT

In order for students to engage in argumentation, they must have a common set of criteria that they are using to evaluate one another. Without this shared criteria, arguers will be questioning and emphasizing different aspects of the argument (Cobb, Stephan, McClain, & Gravemeijer, 2001); they may not be attending to the same features. Thus, beyond asking questions and creating social contexts that motivate and enable students to engage with one another's ideas, we must help students develop shared criteria for evaluating one another's explanations.

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

Other strategies for making the criteria of scientific argumentation explicit exist throughout the research literature. One strategy is to call out the components students must have in their arguments. For example, Osborne et al. (2004) supported students by giving them sentence stems that identify the components of a complete argument. Our design work follows a similar approach, giving students an instructional framework that highlights the components of an argument, including evidence (Bruozas et al., 2004; McNeill et al., 2004a; McNeill, Lizotte, Krajcik, & Marx, 2004b). A second strategy is to scaffold students' construction of the argument such that the criteria are explicit in the students' work. For example, Bell and Linn (2004) and Toth et al. (2002) both developed argument map software tools in which students are asked to explicitly connect their evidence to their claims. These tools make the criteria explicit by drawing students' attention to the connection between their evidence and claims. Finally, we see Herrenkohl et al. (1999) providing their students with sample questions they might ask one another when evaluating one another's arguments.

Our current design approach is to draw from each of these strategies, providing students with an instructional framework that focuses students' attention on their claims and evidence. We then transform this framework into a series of questions that students can ask each other as they make sense of their different explanations and work to reconcile those differences (Kenyon & Reiser, 2006). Through this, we hope to help students develop a common criteria for engaging in scientific argumentation.

Given our practice-based perspective on argumentation, it is unsurprising that each of these design strategies rely on the others: without a richer context the activity structures are unnecessary because the question does not motivate argumentation. Further, without activity structures that motivate argumentation, the explicit criteria becomes unnecessary because the students have no need to evaluate one another. Similarly, without this rubric, students will have difficulty engaging in the richer questions and activity structures because they won't have common evaluative criteria.

Applying these Design Strategies

We have spent the last year, working with a 7th grade teacher to redesign an existing grade ecosystems unit (Bruozas et al., 2004) in order to test our design strategies. The original version of this eight-week unit was designed to support students as they constructed "evidence-based scientific explanations." These explanations were typically one paragraph long and contained a claim supported with evidence and scientific principles. While the existing design supported students in applying ecosystems concepts to understanding interesting phenomena, it did not foster the practice of scientific argumentation. Thus, our redesign focused on the three design strategies, described above: 1) create a need for the students to use evidence when constructing and evaluating claims 2) create a need for students to attend to one another's claims and evidence 3) make the evaluation criteria explicit.

Our cooperating teacher enacted this unit in three classes, in a large Midwestern city. We observed and videotaped the enactment in one of the classes. This class contained fifteen students, eleven girls and four boys, from diverse backgrounds. We met with the cooperating teacher weekly to evaluate and revise the lessons, in response to the students' and teacher's needs. While observing, the researchers would occasionally work with the students, asking leading questions and facilitating discussions. We conclude this paper by briefly providing an example of argumentation that emerged in this class – describing the activity and the ways in which students engaged in the scientific argumentation.

About three weeks into this unit, students begin working with a NetLogo (Wilensky, 1999) computer simulation of a mini-ecosystem. This ecosystem contains foxes, rabbits and grass. Students begin by watching the population fluctuations, understanding how changes in each population affect the others. The students then add an unknown organism, an "invasive species," to the ecosystem. The students are asked to determine what the invader is, based on the population fluctuations that indicate what it eats and which organisms eat it. We designed this activity to address the above design strategies:

1. *Create a need for students to use evidence:* In order to answer the final question (what is the invader?), the students had to interpret the data. This immediately goes beyond a surface level identification and regurgitation of data by asking students to apply data in order to determine the relationships between the organisms. In this way, the question the students were investigating created a need for them to use evidence.
2. *Create a need for students to argue:* We used variations on the Argument Jigsaw and Whole Class Debate activity structures in order to create a need for students to attend to one another's claims and evidence. In this class, the students worked in pairs to study the NetLogo model and construct initial arguments about the identity of the invader. The teacher then reorganized the students into larger groups that all agreed on the initial claim (e.g. "the invader is an omnivore"). In these larger groups, the students used the guiding questions (described below) to construct arguments that would convince their classmates about the invader's identity. Finally, they engaged in a Whole Class Debate, presenting their arguments and questioning one another. In this class, the culminating debate was a driving force that created a need for students to ensure that their argument was robust.
3. *Make the epistemic criteria explicit:* Early in the unit students were introduced to the instructional framework for constructing and defending scientific argumentation. This framework guided the construction of their arguments in the NetLogo. Then, before the Whole Class Debate began, we worked with the students to construct a list of questions they could ask each other in order to evaluate one another's arguments. These questions included items such as: "Why should I believe that your evidence is not opinion?" and "How is your evidence connected to your claim?." These questions and the instructional

> framework were designed to draw students' attention to the epistemic criteria of scientific argumentation: claims must be defending by evidence.

Throughout this lesson, students were engaged with the NetLogo model. This is unsurprising as it contains many videogame elements that, at first exposure, students tend to find interesting. However, we were excited to find the students going beyond engagement with the video game aspects of the activity, in order to engage in argumentative discourse.

We illustrate the students' participation in the scientific argumentation by offering excerpts of one group's presentation during the Whole Class Debate. This was the first of three Argument Jigsaw/Whole Class Debate activity pairings. Throughout each of these activities, we saw students engaging with one another's ideas in a way similar to this example. We chose this example because of the clarity with which the presenters are relating their own claim to those of their classmates and because it provides a representative example of the types of questions that were asked during Whole Class Debate.

The students in this group determined that the unknown invader was an herbivore that ate the grass. This conclusion is correct, but differs from the agreed upon conclusion in the classroom; most students believed that the invader was an omnivore eating the rabbits and the grass. Both of these claims account for the most salient data in the model: the rabbits and grass populations both decrease. However only the herbivore explanation can account for the fact that the invasive species can live without rabbits present.

In the following excerpt, Michael begins by presenting the claim that the invader is an herbivore:

> Michael[6]: "People were saying that the invaders were eating the rabbits and that's not true. What really happened is the invasive species and rabbits were competing for food. And since there were more invasive species than rabbits they ate all of the grass and there was…"
>
> Janelle (his group member) jumps in during his pause, they say simultaneously: "no food for the rabbits"
>
> Michael: "so therefore, the rabbits all died. And to prove this even further, we set it up so that the invasive species took the place of the rabbits. We set it up just how we would do the rabbits, more invasive species than foxes, 0 rabbits and they still lived the same way as they would with rabbits."
>
> Teacher: "ok, questions?"
>
> Class: "oooh, wow" [class laughs]
>
> Michael: "In other words, the invasive species are vegetarians, just like the rabbits. They do the same kinds of things the rabbits do, but there is more of them."

Michael and Janelle begin by stating their claim in opposition to a commonly agreed upon claim: the invasive species makes the rabbit population decrease by competing with

[6] Student names are changed throughout this paper.

it for food, not by eating it. They then present evidence in which the invader takes the place of the rabbit in the ecosystem. While not conclusive, this evidence clearly supports the claim that the rabbit and invader eat the same food. Their class hesitates when prompted to ask questions; this was a coherent argument that was forcefully presented, making it difficult to question. Eventually the students begin asking questions, such as the following exchange:

> Questioner 1: "where did you get your evidence from?"
> Janelle: "NetLogo"
> Michael: "the computer, we went on NetLogo the computer and we set it up just like the rabbits…"
> Questioner 2: "excuse me, how do you know that your invasive species is a vegetarian?"
> Janelle: "because it only ate grass. The foxes didn't die at all, only when the invasive species died."

During this question and answer period we see the students pushing against their evidence, asking first for the source. It is important to remember that the students were provided with a list of sample questions to help guide their questioning process. This is one of those sample questions. While Janelle's answer to this question implies frustration (particularly her dismissive tone when giving her answer), the question is meant to encourage the students to question the reliability of the evidence. The second question is more substantive, asking the presenting students to provide additional evidence that the invasive species eats only grass. Interestingly, Janelle's answer introduces new evidence, not seen in their presentation. Janelle's evidence demonstrates that the invader does not eat the foxes but that the foxes do eat the invader. This is further support for their broader claim that the invader fits in the same ecosystem niche as the rabbit and indirectly supports their claim that the invader does not eat meat.

Clearly this exchange isn't an ideal case of scientific argumentation. The biggest limitation with this presentation is that the students' questions do not identify weaknesses with the presentation instead the questioners simply ask the presenters to restate the information. Given this limitation, we selected this exchange to demonstrate the student engagement in scientific argumentation because of two key elements. First, unlike the typical presentations seen in classrooms, these presenters are attuned to their audience; Michael begins his presentation by explicitly contradicting the claim largely accepted in this class. This move demonstrates that he is engaging with his audience; attempting to start where they are and help them understand his new, provocative, claim. Secondly, the audience engages with this presentation. We see this at the conclusion of the presentation when the students laugh; they appear a bit overwhelmed by the forcefulness with which Michael and Janelle presented their data. We see the audience attention to the presentation again during the question and answer period when the second questioner directly states their claim: "how do you know it is a vegetarian." By restating the claim, this student has demonstrated that she is following the presentation.

We believe that the strategies we implemented in this lesson helped the students engage in this argument, as both presenters and audience members. First, the question the students investigated was rich enough to require that students had to go beyond reciting data, the population fluctuations, and instead apply it to construct support their claims. The effectiveness of this strategy is apparent in Michael's discussion when he uses his evidence to "prove this even further." Second, the activity structures put students in positions to question one another. We see this strategy emerging in the question and answer period; the questioners and presenters were talking directly to one another, they were not talking through their teacher. Finally, we provided the students with sample questions to help focus them on the alignment between one another's claims and evidence. In this lesson, these questions appear directly in the questions the students ask one another.

Summary

Our design strategies are based on the assumption that traditional classroom norms can inhibit student participation in the practice of scientific argumentation. Given this assumption, we as designers must create opportunities for the students and teachers to transform their classroom norms so that they more closely align with those of scientific argumentation. At the crux of this approach is the idea that students must feel an intrinsic *need* for these new norms. That is, the norms of the new practice must make sense in the context of the classroom. For example, the goals of traditional classrooms encourage students to demonstrate individual mastery over the teacher's knowledge. This neither necessitates nor motivates students to engage with one another's ideas. Thus, in order to foster argumentation we must create a need for students to go beyond this demonstration of knowledge in order to attend to one another claims and evidence.

We have developed three design strategies to support students and teachers as they transform their classroom norms. First, we create a need for students to go beyond the recitation of data, they must apply it as evidence to solve a problem. Second, we create a need for students to engage with one another's ideas in argumentative discourse. Finally, we support these conversations by helping students develop explicit epistemological criteria for constructing and evaluating scientific arguments.

The results of our pilot study are encouraging in that the students in this class engaged in important aspects of scientific argumentation – they engaged with one another's ideas and used evidence to evaluate and question one another. However, this study was done in an ideal setting with a teacher that is highly sympathetic to our design goals. We are currently working on a more robust test of these design strategies, working with three urban classrooms to understand the norms that emerge. Through this design research we hope to better understand these design strategies, addressing question such as: What does it mean to have a "rich context?" What are the necessary and sufficient conditions for questions that are rich enough to inspire argumentation? How do those students that do not find argumentation to be a supportive learning environment react to these activity structures? What can we do to support these students? And, how do teachers support students as they learn to offer and receive constructive feedback?

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