

Fostering meaningful scientific argumentation practices through ongoing classroom interactions

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Abstract: Specific sets of structural elements are often taken as the criteria for assessing students' argumentative abilities and designing curriculum or teaching strategies that promote classroom argumentations. In this paper, we take issue with such oversimplified, research paradigm, arguing for the necessity of examining students' argumentative practices as rooted in the complex, evolving system of classroom. Employing a sociocultural-historical lens, we illustrated through close discourse analysis how a high school biology class continuously builds up affordances and constraints for their argumentation practices through interactions. Whether argumentative conversations can take place in certain situations and sustain, and how the teacher and students participate in it have much to do with the learning goals, norms, teacher-student relationships and epistemic stances constructed overtime. Based on such findings, we suggested that the field should consider promoting classroom scientific argumentation as a long-term process, requiring supportive resources to be developed through continuous interactions.

Argumentation: Structure, Skills and Classroom Norm

Over the last half century, scholarly views of science have shifted from a dominant focus on experimental processes to increasing concerns about its socially constructed nature (Driver, Leach, Millar & Scott, 1996). Conceiving science as ongoing human activities, philosophers of science have suggested scientific argumentation as playing a central role in the production of scientific knowledge, constituting a core element of scientists' practices (Latour & Woolgar, 1986; Fuller, 1997). Following in suit, reforms in science education has made efforts to promote scientific argumentation practices (NRC, 1996, 2000; Kelly, Druker, & Chen, 1998; Driver, Newton, & Osborn, 2000).

A framework commonly used by educational researchers to conceptualize argumentation derives from Toulmin's (1958) *Use of Arguments* (Bell & Linn, 2000; Driver, et al, 2000). While the original purpose of Toulmin's work was to challenge the traditional, inference-centered view of argument with practical emphasis on justification, it was reduced to a model consisting of the typical structural elements of argument and their functional relationships. In short, *data* referred to the evidence used to support a *claim*—the point-making statement, and warrants were the logical statements bridging *data* and *claim*. (Other elements of his framework -*qualifier*, *rebuttal* and *backing*—are less frequently employed in educational research).

This general account of formal argument has been modified into important tools for examining and evaluating argumentation practices in classroom (Kelly, et al, 1998; Jime'nez-Aleixandre, Bugallo-Rodri'guez, & Duschl, 2000; Erduran, Simon, & Osborne, 2004; Dawson & Venville, 2009). Some directly applied a Toulmian model as the coding scheme, analyzing argumentation discourse for how frequently specific structural components got involved (Kelly, et al, 1998; Jime'nez-Aleixandre, et al, 2000); others developed scaling measurements, assessing student arguments based on structural completeness (Erduran, Simon, & Osborne, 2004; Dawson & Venville, 2009). With similar emphasis, early work from Kuhn (1991, 1993), though not employing a Toulmian framework, also linked argument structure with cognitive skills in coordinating theoretical claims and evidence.

Findings from research focusing on argumentation structure point to both the incomplete structure of students' arguments and the weaknesses in students' argumentation skills. For example, many found that students often argued by stating their claims without justification through warrants and data (Jime'nez-Aleixandre, et al, 2000; Dawson & Venville, 2009). Through interview studies, Kuhn (1991, 1993) suggested that adolescents and lay adults lack the skills to distinguish data and theoretical explanation of data. These deficiency explanations motivated the development of specific curriculum and instructional strategies for initiating, supporting and scaffolding students' argumentation practices, such as explicit teaching of general reasoning patterns (Zohar and Nemet, 2002), using open-ended argumentation prompts (Erduran, Simon, & Osborn, 2004), creating opportunities for peer or small group discussions (Erduran,

Simon, & Osborn, 2004), and replacing written scaffolds with teacher introduction of an explanation framework (McNeill, Lizotte, Krajcik, & Marx, 2006). Through pre and post assessments designed to measure the structural completeness or the usage frequency of certain components, these interventions showed satisfactory changes in students' argumentation discourses.

While this research proves prevalent, its guiding framework and overarching goal greatly limits the scope of understanding on classroom scientific argumentations. As a structural account of formal arguments, Toulminian scheme provides neither tools nor language for analyzing argumentation as a goal-driven, socially constructed discourse phenomenon, embedded in either classroom discourse or the broader discourse of science (Kelly, et al 1998; Driver, et al, 2000). Judging the quality of a scientific argument according to structural features, in separation from its functional role and the cultural-historical contexts in which it is rooted, can be misleading. First, as Kelly et al (1998) suggested, language can be flexibly used in conversation, and the need for justification is often shaped by the interactive history and shared knowledge. He noted it was difficult to identify components of an argument without considering the related contexts and conversational dynamics, and even more difficult to make fair inference on individuals' abilities or skills in argumentation based on the structure of their arguments in an interactive discourse.

Second, the value of argumentation in science rests in its power to resolve scientific discrepancy (Driver, et al, 2000). If argumentation skills get foregrounded and established as the learning goal, but learners are not pursuing something that would raise the need to argue, we have little to ensure that argumentation gets developed as a useful discourse tool that students can draw on, and risk making parts of an argument another school-defined convention.

With such concerns, some scholars suggested that scientific argumentation should be established as a classroom norm (Driver et al, 2000; Engle & Conant, 2002). They called for argumentation to become evident in discourse patterns that permeate a variety of classroom activities, emerging naturally as part of students' regular sense-making interactions. In alignment, recent research has begun to investigate the complexity of classroom argumentation phenomena, taking into account multiple, interdependent factors of the learning environments. Studies on how learning contexts motivate engagement in argumentation suggested the important roles of factors such as social norms of classroom interactions (Berland & Reiser, 2009) and epistemological resources (Louca, Elby, & Hammer, 2004). In a case study of an emergent and lasting classroom argumentation, Engle and Conant (2002) demonstrated how a class' disciplinary engagement was constructed through continuous effort in fostering a learning community that encompassed such features as attitude and values towards controversial ideas, positions and roles of students, accountability for disciplinary norms, and supportive classroom resources. This line of research conveys a resounding message: to understand classroom affordance of meaningful argumentation practices, we need to look into the non-linear, multifaceted development of classroom learning environments.

Following this train of thought, our study explores how classroom norms conducive to scientific argumentation take shape and give rise to students' sense making interactions in a high school science classroom. From a sociocultural-historical perspective (Vygotsky, 1978; Engestrom, 1987), we view learning as continuously occurring in interactions between the social and individual planes, mediated by artifacts and sociocultural contexts and developed through the interactive history of the specific group and broader communities. From there we ask these questions:

What affords or constrains the use of scientific argumentation in science classrooms?

How do classroom affordances and constraints of argumentation get constructed over time through classroom interactions?

The lens of localized activity theory

The dynamic and evolving view of classroom activities came from the theoretical lens of Activity Theory (Engestrom, 1987, 1999). According to this model, in a continuously changing activity system, collected subjects conduct object-driven activities that provide the momentum for its changes. Their actions and interactions towards the object are mediated by material and symbolic artifacts as well as factors from the broader contexts such as rules, community and labor division. Localizing this framework to fit the specific features of my subject, we consider a classroom as an activity system in which teacher and students carry out activities driven by overarching and specific learning objects, or other classroom/school related objects (such getting familiar with each other, setting dates for exam). These activities are conducted employing

material tools (such as textbooks) and communicative tools (such as language). Contextually, activities are also shaped by norms and routines of a classroom (rules), values and norms held by the educational system (community), as well as the roles of and the relationship between teacher and students (labor division). I referred to all these factors as *classroom mediational resources*.

The term “resource” has already gained various meanings within the field: Hammer (2000) employed it to describe the conceptual and epistemological “knowledge in pieces” (diSessa, 1988) brought to learning by individual students. Crawford, Kelly, and Brown (2000) used it to refer both to individual knowledge of science practice and the artifacts affording science practice; Engle and Conant (2002) broadly defined “resources” as supporting settings ranging from available space of class time to classroom constructed artifacts and norms to modes of discussion. In this study, the meaning of *resource* is closer to Engle and Conant’s (2002) use, but broader (e.g.: to include epistemological resources), and focuses on a functional common ground, that is, when functioning together, they afford certain interactions and constrain others.

Mediational resources get constructed in interaction, both explicitly and implicitly. Explicit construction occurs through actions/interaction with clear goals of setting up resources for current and/or future learning activities. Such situations, do not appear as common as implicit constructions, in which the interactions are not focusing on setting up resources, but as certain discourse and participation patterns, compatible values, norms and relationship that emerge and hold potential to mediate current and future interactions.

Within this framework, scientific argumentation is a general form of interaction serving the objects of different classroom activities. For such interactions to emerge, the class needs to develop shared understandings of when argumentation is allowed, what type of language to use and how to participate. The norm of argumentation also needs to be compatible with other classroom norms, both content wise and context wise. To illustrate the establishment of such argumentation “norm,” we have to explore the complexity of an evolving classroom system. The influence of mediational resources for argumentation extends beyond structural concerns to content, purpose, values and participation patterns of specific argumentation interactions.

Data Source and Methodology

To investigate classroom affordances and constraints on scientific argumentation, we videotaped a teacher’s (Sarah’s) class for a full semester (September 2008- January 2009). The class was an ethnically diverse, honor’s level, biology class, comprised of 24 students, with a roughly balanced gender ratio and a mix of 9th, 10th and 11th grade students. At the time of this study, Sarah was in her 3rd year teaching biology in a large, suburban-urban fringe public high school. She had participated in a university-based collaborative research project that sought to better understand teachers’ curricular modifications. During that project, she was identified by researchers as relatively good at scaffolding student argumentation and as a teacher who strove to facilitate students’ participation in other scientific inquiry practices, despite institutional pressures associated with standardized curriculum guides and high-stakes testing that could focus attention elsewhere.

Our analysis of classroom data focused on interactive learning discourses, mainly speech, but including contextualization cues (Gumperz, 1982; Duranti & Goodwin, 1992) such as eye gaze, gesture, writing, and visual representation on the board. Initial analysis entailed cataloging summaries of interaction content of all classroom video, in one to five minute intervals. The thickness of descriptions (Geertz, 1973) was determined by the richness of the discourse data and how closely it related to the interest of this research—thicker where students shared ideas and built arguments.

We began to identify discourse patterns and shifts on different levels: 1) General discourse structure, such as triadic dialogue (Lemke, 1990), reflective toss (van Zee & Minstrell, 1997), and back-and-forth argumentation (Cazden, 1988); 2) Ways in which productive learning interactions were initiated and maintained, which included type and amount of teacher scaffolding; 3) (i.e.: scientific language and everyday language (Lemke, 1990)); and 4) Patterns of expressions (common words or phrases).

Episodes bearing patterns or demonstrating shifts in patterns were transcribed and subjected to closer analysis in order to draw out meanings of discourses and gain insight into the social processes underlying the learning interactions. (Gee, 2000; Erickson, 2004; Kelly, 2005). To do this, we summarized participation and discourse features of each episode. We then worked backwards (and forwards) to try to identify an interactive history through which parallel features emerged. Analyses across episodes helped

bring out possible meditational resources, how they were constructed and what work they accomplished for classroom learning.

Data Analysis

To illustrate how such theoretical and methodological frameworks guide our analysis, we draw on several representative argumentation episodes from the class we studied.

An Illustration of the Classroom Argumentation “Norm”

The first one took place during a class review of biotic relationships (predation; commensalism; mutualism; parasitism), which is a month into the fall semester and a week after they took notes on that topic. The teacher Sarah asked students to name and explain the meanings of different biotic relationships. After she confirmed that parasites usually do not kill the host, one student threw in a challenging question and a discussion ensued:

Acer: if there is like a parasite or something in the prey or whatever dies, like, because of it, would you call it predator or what or still parasite?”

Charles: like you could die from mosquitoes... like the disease they carried...

Sarah: so the disease they carried like kills them, not the mosquito.

Charles: well, the mosquito bit the person.

Students: Yeah...

Christine: Yeah, but it wasn't/

Sarah: but the bite didn't kill the person.

Christine: It is the disease...

Acer: Um, What, wha... isn't a virus like a parasite?

Charles: but they inject the virus that caused the disease.

Sarah: So, here is, if I were gonna argue back with Acer. He just said isn't a virus like a parasite. If I'm gonna argue back...Does anybody else wanna argue back?

Students: No.

Sarah: I'm gonna argue that/

Charles: Because virus isn't an organism.

Sarah: some people would not consi...virus is kind of falling in this iffy place where we are not sure we should call them alive or not alive. So I would argue that is not a relationship between two living organisms. I would say that there are always exceptions to the rule, like, Tim said, “That's rare.” There are exceptions though. So usually parasites don't kill their host. If they did kill them, I don't know, maybe you would want to call it a predator 'cause it hunts it and kills it.

Tim: but usually it just doesn't happen

Tim: like it would be predator and prey if that in that form. [inaudible]

Sarah: what did you say?

happens a lot, but it can happen sometimes but usually the other animal doesn't die, so it is just parasitism.

Charles: Oh, my gosh, he sounds so smart. [class laughter]

This collaboratively constructed scientific argumentation flew through shorthanded and co-constructed arguments, demonstrating the students' ability to engage in scientific argumentation and also reflecting their conceptual understanding of the subject. As Acer problematized the demarcation between parasitism and predation with a particular situation—a parasite in a prey that dies from it, he made an argument based on a hypothetical overlap between the two categories. This required certain conceptual understanding of both types of relationships. . The exchanges between the teacher (and Christine) and Charles showed that they both have certain understanding of the pathological mechanism behind mosquito-borne, transmissible disease, but have different interpretation of the case in terms of what is the killer: while the teacher identified the disease rather than the mosquito as the direct cause of death, Charles defended his argument by emphasizing the mosquito's initiator position in the causal chain—it “bit the person” and “injects the virus.” The argumentation shifted when Acer brought up virus as an example for the situation he described. Charles and the teacher both argued through denying virus' status of living organism and excluding it from the category of parasite, which is the precondition for it to be considering as a candidate for the situation they talked about. By introducing the “iffy place” about virus' being alive or not, Sarah indicated the debatable nature of her rebuttal, and also took a step back, acknowledging the possibility of a loose boundary—“If they did kill them,” “maybe you would want to call it a predator 'cause it hunts it and kills it.” Tim then jump in and showed an understanding of the probabilistic meanings behind accident and normality

While this episode shows merits if examined in terms of argument structure or content, its significance extends far beyond that. First, the argumentation is initiated by a student's challenge of the canonical boundary between parasitism and predation, which had been established by the teacher in previous class sessions and confirmed just prior to this episode in a teacher-student interaction. Such moves are rare, in our observations and in the common patterns of classroom argumentation interactions recorded by the literature, as usually argumentations get start with open question and without “correct answer” being given (Engle, 2002). Second, this conversation occurred during a review activity, where checking conceptual understandings and knowledge of terminology is far

more typical than engaging in scientific argumentation. Third, the students brought up arguments on their own rather than following specific probes from the teacher. While the teacher's scaffolding moves were very limited (The main move she made is bringing Acer's argument to the class' attention and ask "Does anybody else wanna argue back?" which is followed by the "virus is not alive" argument co-made by Charles and herself.), the students attended to the ideas from each other and from the teacher. Lastly, the nature of the teacher's participation is distinct from more commonly adopted roles: she was an arguer in the field, actively constructing her own argument. Though some might find some authoritative flavor in her arguments, we noticed that the students treated her ideas on par with their peers' arguments rather than as ones to accept. They argued with her without hesitate, clearly demonstrating their understandings and critical thinking.

We argue that understanding the features listed above are important for explaining how argumentation took place at the moment. We would also argue that these are the indicators that certain argumentation "norm" has established in this class, so that argumentation can naturally emerge and contribute to the class' sense-making process. The immediate contexts of this episode, however, does not explain what gave rise to these features. When examining this episode as embedded in the interactive history of classroom, we have identified previous episodes that share or contrast this episode in certain discourse features. Through comparing multiple episodes, we analyze how mediational resources conducive to scientific argumentation get constructed, and contribute to the features and participation patterns seen here. The following section demonstrated the construction of one piece of such resources.

"Because You Keep on Asking"

While the students attend to the substance of each other's and the teacher's ideas in the parasitism-predation argumentation, this was not always the way they interacted in this class. On the third day of class, in a discussion on "why do we brew tea in hot water?" after the students came to agreement that hot water works faster than cold water since molecules move faster in it, Sarah posed the question: "At the end of all, are we going to get the same product using hot water and cold water?" At first, the class together made the "yeah" sound in a low-pitch, elongated tone, as if that answer was so self-evident. After this question being pushed back twice, only several students still remained in responding, and their answers provided a simple causal explanation for their previous judgment—"it (the tea) would eventually go into water." As Sarah, again, pushed it back to students by explicitly asking for "anybody thinks no?" the following exchanges took place:

Sarah: Does anybody think no, we are not gonna get the same thing?

Dani: (raises up hand)

Sarah: Yeah? How come?

Dani: Because I think that's the right answer.

Sarah: And ... why?

Dani: Because you keep on like, asking that.

Sarah: I'm just trying to get you guys disagree about stuff! One person said something and you were all like, yeah— (she mimicked their lazy tone. The whole class laughed and Tristan put his hand up).

In response to Sarah's push, Dani raised his hand and voted for the "not gonna get the same thing" claim. When Sarah probed for his reason by asking "how come?" he gave no scientific explanation but stated that he thought "that's the right answer." It was after another push from Sarah he shared his interpretation that the teacher's keeping asking when everybody said "yes" must suggest the opposite to be correct. Danny did not receive any counterargument, laughter, or other looks from his classmates; instead, the class remained silent with their eyes fixing on Sarah, implying that they were also waiting for an answer. Sarah did not show much surprise either. Claiming the purpose of "get you guys disagree about stuff," she then imitated and made fun of the way students casually threw away their agreements, indicating that she would interpret such answers as not resulting from critical thinking.

At this moment of the discussion, students did not generate scientific argument. Even the teacher's move to scaffold was misinterpreted as an indicator of correctness. Sarah did not play the arguer role here. Since the students would accept what they thought she indicated, it is reasonable to guess that they were concentrating on getting the correct answer and probably would not stand on equal foot and argue with her.

This conversation did not end there. Students offered an alternative answer, and one student provided a piece of reasoning that would support the claim: there would be less water in tea made with hot water due to evaporation, so there would be a higher concentration of tea. This argument was not taken seriously and respectfully, as the class immediately exploded in laughter and made funny "ohhh" sound and one student even sarcastically stated, "what an awesome answer" with rolling eyes. Sarah, however, ignored the sarcasm and grabbed the idea. She offered the student a chance to repeat his idea to the class and then encouraged him to further his chain

of reasoning.

This discussion ended up with several students claiming that hot tea resulted in a higher tea concentration. Other classes of Sarah's ended up with the opposite conclusions. As Sarah told us in the interview, there was "not an exact right answer such discussion tried to reach." Reasoning-based arguments on either side would count towards fulfilling the object of the activity.

In contrast to the student-initiated predation and parasitism-predation argumentation, although this tea brewery discussion was planned to be an open-ended one, the way the students participated indicated their expectation of a correct answer from the teacher. Instead of thinking critically about the phenomenon or reasoning through ideas, the students pursued the teacher's confirmation. Sarah made much effort scaffolding: first she encouraged argumentation by pushing back reasoning-lacking agreement; she probed students for reasoning, and communicated the purpose of her discursive move; finally, by requesting students to articulate a chain of reasoning, she claimed value for this spark of scientific thinking, and set an example for the class on how to focus on the scientific substance of ideas.

When contextualized in the larger picture of school education and the settings of this classroom, what gets communicated here is much more than what has been explicitly said. By explicitly associating her discursive move with promoting disagreement, and by attending to the scientific substance of an idea the class laughed at, Sarah also negotiated with the class a shift in the general goal and values of science learning. This shift, we would argue, is a piece of resource that could contribute to the ways in which students attended to ideas in later argumentation (such as in the parasitism-predation discussion).

We have identified other resources through comparative analysis of episodes of classroom interactions. Due to the page limit, we summarize them in the findings but would not go into details here.

Constraints on Classroom Argumentation

While Sarah's class has constructed significant affordances for student participation in scientific argumentation, it is not the case that scientific argumentations can be developed towards any direction at any time. We saw constraints on argumentation in that class. For example, the parasitism-predation argumentation lasted for a few minutes and did not develop to its fullest. The conversation was called to an end when students started to challenge the "iffy status" of virus. Sarah's decision to "get back on topic" highlights that not all tangents are fair game, and not all argumentation are permitted. The predation-parasitism exchange showed how the class was afforded to go on tangents, initiating and sustaining argumentation in an activity not particularly framed for scientific debate or open-ended scientific discussion. In that part, the arguments focused on demarcating the concepts of parasitism and predation. However, with tighter objectives of a review activity's object on understanding biotic relationships, redirecting the conversation was not an option. In previous classes, we have observed situations when similar tangential argument got accepted and followed in activity with looser and multifaceted objects (not shown here): for one thing, the activity was set up as a chance for everyone to participate, attending to, challenging and building on each other's ideas; for another, they were trying to make sense of a truly unsolved scenario, which even the teacher was not sure what was going on. This allowed (and actually required) in depth explorations into the details of ideas. In contrast, the unit review activity has a much more specific goal and therefore clearer boundary for tangent, since there was a more to-the-purpose topic to "get back on".

How, then, should we understand such constraints? What contribute to where and when they present? What determine the strength of their effects on ongoing conversations? When tracing back the class' interactive history, we identified mediational resources constructed by the class that would contribute to such constraints.

Research Findings

The major finding of this research, as partially depicted in the analysis above, is a more contextualized account of classroom scientific argumentation. We go beyond evaluating and boosting certain argumentation structures, moving into the construction and functioning of argumentation-related classroom mediational resources. Our analysis demonstrates how classroom norms, rules, teacher-student relationship and discourse patterns formed through interactions, some of which even seem unrelated to argumentation, can later mediate students' participation in argumentation.

Through analysis, we have identified resources that could organize and mediate the class' participation in scientific argumentation in activities not framed as ones for practicing argumentation. These include: A comfortable-to-share and whole-person-respected classroom relationship; general goal and values assigned to the substance of

ideas; the participating norm of “talk about shared ideas;” and repeatedly conveyed epistemic messages that biology concepts “always have exceptions.”

We have also noted the tenuous nature of the classroom argumentation “norm” in the face of system-wide pressures, like common curricula and high-stakes testing. We identified interactive history the discourse constructs of “fun” and “serious/boring,” which set different participation norms for activities focusing on substance of scientific ideas and activities focusing on test preparation. As unit exams and the final state assessment became more impending, we saw significant changes in the teacher and students’ participation patterns, including a drop in the frequency and length of student-initiated argumentations. Some other constraining resources included the different values and different nature of knowing attached to different biological subdomains and the classroom norm for resolving goal conflicts.

Research Significance and Implications

We chose to write about this classroom, not just for the distinct argumentations it affords, but also for the weight of realness it bears. The word “realness” here has two folds of meanings. One points to the systemic pressure this classroom has to deal with—since classrooms cannot always be experimental sites in vacuums. In order for the goal of scientific argumentation to organize classroom learning in a meaningful way, it has to coordinate with many other objects that orient classroom activities. The other points to the goal of promoting argumentation in science education: to construct a useful way that affords students’ sense making process, rather than as a performance to satisfy researchers’ criteria, then researchers, need to better situate the practices of argumentation in the broader fabric of schooling and science.

This study aims to capture how classroom argumentation “norm” grows out of (or fades away through) sequential classroom interactions. As the story of Sarah’s classroom unfolds and as our analysis goes deeper and more thorough, we identified mediational resources that contribute to the affordance and the constraints of argumentation practices in this classroom. This provides a reference of things to account for in establishing the classroom argumentation “norm”. For teacher educators, this study suggested the necessity of attending to continuous classroom discourse and the long term consequence of interactions. Considering classroom interactions as the process of constructing learning related, shared mediated resources may help teachers and teacher educators to reflect on teaching practices and understand teaching effectiveness from a more constructive, long-term perspective. While activity theory has established theoretical account of how activity system can evolve locally on itself, little work has been done to illustrate such process with data. Through thick description on the construction and functioning of shared mediational resources in science classroom, this study also provided a concrete account corresponding with such theoretical processes.

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