Chapter 13
Beyond Argumentation: Sense-Making Discourse in the Science Classroom

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Introduction

Science classrooms are complex ecosystems of norms and practices that develop over the life of a classroom community. Since the late 1980s, with the emergence of learning theories focused on communities and their practices, there has been an increasing emphasis on creating activities in science classrooms that better reflect the practices of the science community. The idea that elementary and secondary science students should be acculturated into the practices of science as part of learning the content of science is now *de rigueur* in our field. However, the specific way this is instantiated or characterized differs from approach to approach. For example, inquiry as characterized in the National Research Council (2000) is one way that processes and practices of science are described. The essential features of inquiry (Table 2.6, p. 29) include attention to evidence, ability to communicate scientific ideas, and engagement with scientific questions. The emergence of the nature of science as a seminal part of science instruction—either explicitly or implicitly—is another form of characterizing the community practices of scientists. One component that these different perspectives agree upon is that evidence and argument are central to the practices of science. Over the past decade, a strong vein of research in science education has emerged focused on the scientific argumentation practices of students. Initially building on the work of philosophers, in particular Toulmin (1958) and his description of argument, there has been a sharp increase in attempts to both characterize the nature of argument constructed by students as well as develop curricular and pedagogical supports for students' scientific argumentation.

In this chapter, we suggest that—while important—an increasingly specific focus on argumentation in student discourse has significant limitations in terms of supporting student learning, developing students' understandings of the way scientists practice within their community, and supporting the development of productive

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norms and practices in communities of science learning. Research in this area shows signs of increasingly specified and calcified definitions of argument and how discourse in science classrooms is analyzed. There are both social justice and equity concerns around a narrow pedagogical focus on one type of student discourse and significant analytical limitations in terms of understanding the quality and productivity of students' classroom science discourse. We begin by providing examples of classroom science discourse as a context for our comments. Following that, we briefly characterize the trends in science education research, including some of the work on productive discourse done outside the specific line of argumentation research. We close by suggesting scientific sense making as a broader perspective on science discourse practices that would be more productive both to support science teaching and learning as well as science education research.

Sense Making in Classroom Discourse, Part 1

The following short episode illustrates not only the complexity of classroom discourse—showing the potential of viewing reasoning from an argumentation point of view—but also the confusing nature of real-time interpretation of discourse in a sense-making situation. In this case, a chemistry class is discussing mole ratios and is attempting to make sense of the reaction of zinc and sulfur. Prior to this conversation, students had been working on an extended analogy over multiple days where they were making cookies using different ingredients to get a sense of ratios and recipes. This recipe making is then connected to the mole concept as a unit of measure that describes the recipes of chemistry. The students have been given an amount of zinc (6.54 g) and are asked to determine how much sulfur they need for a reaction. Different groups have come up with different solutions and reasoning and the groups are debriefing as a class to determine a solution to test. This selection of transcript comes at the point the students are working in groups evaluating the merits of at least two possible solutions that have been suggested by the class. As the students discuss the two solutions, the teacher enters to point out aspects of the argument in an effort to guide the students to her preferred response—or at least direct them toward certain evidence.

1. Teacher: What do you think? [asking students in one group about another group's idea]
2. Alex: I don't think it [the idea presented] will work.
3. Teacher: No? Who . . . who's do you like better—this one or the other one?
4. Colin [pointing with pen over his shoulder at group A]: That one.
5. Alex: Theirs [also indicating group A] made more sense.
6. Bonnie: Like the one thing bothering me was like the one box over there [referring to sulfur on the Periodic Table] . . . like, when you move to the right . . .

7. Teacher: Wait! Wait! What? Wha- . . . what? Danielle . . .[Danielle, a member of group A, turns around]. Question here . . . for you. [To Bonnie]: Ask [Danielle] that.

At this point in the discussion, the teacher recognized that for one student group to be able to understand a key aspect of reasoning in chemistry, they would have to understand relevant knowledge already established by another student. The teacher sought to enter this into the student groups' conversation by directing Bonnie to ask Danielle the question about the relative position of elements in the periodic table (turn 7), knowing that this would provide key information about the relative reactivity of the elements.

8. Bonnie: Oh. Why'd you move 16 blocks over? What made you decide to do that?
9. Danielle: Because sulfur [points left index finger toward Periodic Table] is more reactive [makes gesture where she moves right index finger slightly up then to the right]. They're more reactive as you go over. . . and up.
10. Bonnie: Oh. Okay. [Said with some uncertainty]
11. Danielle: [Turns around to engage with her group]
12. [Bonnie along with her group, Alex and Earl look at the Periodic Table] Although Bonnie's question is "answered" by Danielle, Bonnie showed some uncertainty and it is unclear whether this exchange has forwarded her thinking. Nevertheless, she focused on her group, only to have Earl again seek clarification from Danielle:
13. Earl: Wait. "Over and up"?
14. Alex: Yeah—what do you mean by "over and up"?
15. Bonnie: Like, sulfur's more reactive than zinc.

Bonnie translated Danielle's "up and over" interpretation in terms of chemical reactivity—knowledge that is potentially relevant to solving the problem at hand. Alex was not satisfied with this explanation and again sought Danielle:

16. Alex: What do you mean by "over and up"?
17. Danielle: Like, reactivity increases to the right and up.
18. Alex: Yeah.
19. Fiona: Francium to fluorine [points to the Periodic Table].
20. Alex: Yeah, so did you go from, like, where potassium is over to zinc and then past zinc to aluminum and then to sulfur?
21. Danielle: Over and up.
22. Alex: Okay.

This ended the second exchange regarding how to interpret the periodic table. The talk suggest that the two students, Alex and Danielle, were seeking ways of understanding each other and Danielle's initial interpretation of how translations on the periodic table relate to chemical reactivity.

23. [Both Alex and Danielle turn back toward respective groups]
24. Earl [talking to Bonnie]: I don't even . . . I don't know why they did that.
25. Bonnie: I don't . . . yeah.
26. Alex [after looking at the Periodic Table]: Because when they were explaining it, they said they went twelve over [to Zn] and then, that was it. And then they went from sulfur . . .
27. Bonnie: Yeah [expression of not believing it].
28. Alex: I don't understand it.
29. Colin: I don't understand . . . I don't think they understand it either.

The group that includes Earl, Bonnie, Alex, and Colin do not reach the conclusion suggested and seemingly understood by the other group, as suggested by Danielle's use of the periodic table. The argument was incomplete and not persuasive for this group. There are a number of interesting aspects to looking at this transcript from the point of view of argumentation. First, we see that the nature of actual talk rarely resembles even the most informal arguments—people while engaged in conversational cooperation (Gumperz, Cook-Gumperz, & Szymanski, 1999) rarely make explicit all the details needed for a tight philosophical argument (Kelly, Druker, & Chen, 1998). Furthermore, in this case, the speakers are uncertain and still in the process of attempting sense making. Second, while we could identify aspects of the argument that are missing, there is more going on than just making and understanding an argument or set of arguments. There are two possible solutions put to the groups. The groups have differing interpretations about the respective merits of the solutions when the teacher directs one member of one group to pose a question to another. Group members have a history, with recognition and reputations for knowledge and problem-solving ability. Furthermore, as the teacher marked one student as possessing relevant knowledge, this differentiated the students' interpretation and added status to the knowledge of Danielle and her problem-solving path. Third, the teacher is doing discursive work to set up the arguments in particular kinds of ways. She set the two solutions (although they were generated by the students), sent the student groups to work, and favored certain ideas as they emerged and marked them as significant. Some arguments are favored and achieve status by the ways the teacher positions students in the class. The respective merits of the substantive argument, both in terms of the quality of its reasoning and evidence and also its normative correctness, is only part of the story; such arguments occur in the flux of everyday life where substantive evidence does not stand alone, but is rather talked into being by how such evidence is accomplished and made significant to the speakers through interaction. It is critical to understand that seen through the lens of argumentation there is very little quality discourse occurring here, but viewed through the lens of scientific sense making there is a great deal of interesting intellectual work being done.

Still Making Sense? Classroom Discourse, Part 2

The following section of the transcript continues as the teacher is bringing the class to closure and is attempting to connect a number of student ideas together to create an understanding of the core mole concept. She begins by returning to Danielle (and her groups') solution to the initial question of how much sulfur they need to react with zinc. The teacher begins with the ratio of one-to-one that, at this point, is not focused on atoms, but is rather attending to the mass of the macro elements. The teacher is focused both on the mathematics of the ratio concept, in terms of determining if one-tenth to one-tenth is the same as one-to-one, as well as this issue of mass or atoms being the object of the ratio in chemical reactions.

30. Teacher: Okay, the key came from the atomic mass—just like Danielle said. One-tenth the mass of zinc reacted with one-tenth the mass of sulfur. Did you guys think [points to group B] that anyone else's plan tied in with yours?
31. Anthony: {Inaudible} [shrugs shoulders].
32. Bella: [Laughs at Anthony]
33. Teacher: Or could?
34. Bella: Theirs [nodding head toward group A].
35. Teacher: Whose?
36. Bella: [Tilting her head toward group A]
37. Teacher: Theirs [pointing to group A]?
38. Bella: Yeah.
39. Cassandra: [Shakes head in agreement]

In this example, the teacher was seeking to generate a conversation where multiple ideas can be considered by the students in the class (turn 30)—i.e., a dialogic conversation following Mortimer & Scott (2003). The teacher has made choices to set up a comparison across the groups' solutions. This may lead to an explicit comparison of evidence, and thus a form of persuasive discourse or argument. The discourse form in this case does not readily match well with analytics for considering argumentation. The conversation is heavily reliant on gesture and indexicality (turns 30–39). The conversation is complicated by the choice made by the students to choose Group A for a comparison of respective plans—from a normative science point of view another group's idea was closer to theirs both in terms of the numerical value and the nature of the explanation, a point the teacher may have realized in situ.

40. Teacher [to group A]: What was your idea?
41. Devon: One-to-one.
42. Teacher: One-to-one.
43. Earnest: Balanced equation.
44. Teacher: Okay, one-to-one. Wait, wait—what's that [on the white board] say?
45. Devon [pointing to white board]: Which was {inaudible, but does look at group A}. One-tenth to one-tenth.

46. Teacher: One-tenth to one-tenth. Is that the same as one-to-one [holding both hands up with palms facing]?
47. Devon: Mmhh.
48. Martha: Yeah.
The teacher elicited (line 40) and received a seemingly approved response (line 41), yet chose to reflect the question in a different form back to the students.
49. Teacher: Yeah it is, right. Interesting. Okay, so. . . they're say::ing . . . oh, here's [gestures toward white board] my question. So, why is it one-tenth for one-tenth? And they [group A] have an idea, right. Hmmm. Why one-tenth for one-tenth? Anthony, what's their [group A] idea?
50. Anthony: One-to-one ratio.
51. Teacher: From where?
52. Anthony [2 sec. elapse]: It . . . {inaudible} . . .[Request for re-explanation]
53. Teacher: From where. . .Fanny?
54. Fanny: What was the question? I'm sorry I {inaudible}.
55. Teacher: Your idea—where'd that come from—the one-to-one idea?
56. Fanny [shaking head]: Yeah.
57. Teacher: Yeah, where'd that come from?
58. Fanny: The chemical equations.

In this sequence, the teacher seeks responses from the students regarding the idea of ratio, and especially the chemical equation (lines 58). The students had already identified the one-tenth to one-tenth ratio, but had not used the specific word "ratio." In this section of discourse, the teacher is also trying to build to the idea that this particular ratio can be derived from the chemical equation.

59. Teacher: Equation. So, in the chemical equation for the "Question of the Day"—which you have written down, you can look right at it—it says one-for-one-for-one, right? Yeah [shakes her head]—you know what I mean? Let's look at it. So, it says, "zinc plus sulfur give zinc sulfide" [writes "$Zn + S \rightarrow ZnS$"] so, my ratio here is one-to-one-to-one, because my coefficients out here, right, are one [pointing to Zn], one [pointing to S], one [pointing to ZnS]. See how both those ideas can tie together. So, if your coefficients weren't one-to-one would it still be one-tenth for one-tenth? [1 sec. pause] What do you think? Cassandra [points to her], what do you think?
60. Cassandra: {No audible comment for a couple of seconds; may have been gesture of uncertainty}
61. Teacher: Not sure. Cassandra's saying, "No." Why not?
62. Cassandra [after 1 sec. pause]: I don't know.
63. [A couple of students laugh]
64. Teacher: Not sure? You're right, though, it wouldn't be. Okay, if you had a different ratio in the balanced equation, like one-to-two, you would get one-tenths for two-tenths. Okay. So, both groups actually had really good ideas that tied together. Also, the idea of reactivity isn't totally off, right, because [points to A] does theirs make sense?

The class proceeds toward finalization of the solution; nevertheless, this section of discourse is adequate for the purposes of our discussion. The teacher is attempting to help students with the process of sense making as well as build a consensus by combining ideas and showing how they can complement and build on each other. She is attempting to build connections across a set of concepts (mathematic ratios, chemical equations, nature of how elements react), but at this point has omitted the difference between the mass the students can physically measure and how the respective masses relate to the mole ratios. A great deal of the discourse here is focused on the mathematical ratios, while the science concept that it underlies is in the background as the students discuss the nature of ratios. The students are also grappling with connecting multiple representations, including the equation for the reaction on the smart board, the molar masses on the periodic table, and the discourses including gestures from the teacher and their peers. In all this complexity, there is little that can be directly pointed to as argumentation, especially final form of scientific argumentation (claims, evidence, warrants, etc.); however, again there is a great deal of productive science talks occurring. Given these two examples—as context for our discussion—we now turn to the contrast between sense-making argumentation as ways of framing discourse in science classrooms.

Science Discourse and Practice

Everyday life in classrooms is accomplished through language and associated social processes. As members of a group affiliate over time and build ways of being talking, and acting, common norms and expectations are constructed, contested, and redefined. Groups make sense of their reality through communication and social actions. Thus, ways of aligning evidence in argument emerge from broader ways of being and sense making in a group that are constructed through social interaction (Kelly & Green, 1998). Importantly, the norms created in classrooms provide intellectual space, and potential academic identities, for members of the classroom to draw upon as they engage and participate in group actions. Similarly, in science contexts, opportunities to engage in research and other relevant practices are constructed through social interaction. The cultural aspects of scientific practice have been well documented through the empirical study of scientific communities in such fields as sociology, anthropology, and rhetoric of science (Kelly & Chen, 1999).

Argumentation in science fields is the product of both genre conventions, constructed over extensive time periods (Bazerman, 1988), and one of a set of everyday actions constructed in the moment in particular contexts (Collins, 1985). A scientific argument in a professional journal or presented to colleagues at a research conference represents only one of the many genres and ways of speaking and writing in science. Drawing from the social studies of scientific practice, particularly the anthropology of science (Knorr-Cetina, 1999; Latour, 1987; Traweek, 1988), we argue that the final form argumentation, with explicitly stated evidence tailored to a professional audience, is just one discourse of science and is a particularly structured and formal genre of science discourse. Thus, there are many types of discourse and ways of using language needed to accomplish the work of science. Such discourses vary across audiences (e.g., at the laboratory bench, among colleagues during a discovery, to editors of a professional journal, for a press release regarding new findings), purposes (e.g., thinking aloud to solve a problem, persuading a colleague, defending published data), and venues (e.g., PowerPoint to laboratory group, email to collaborator, discussion with a student). Thus, while educational reform has called for emulation of scientific practice in educational settings, there has not been careful analysis of the range and typicality of such practices. Often, educational reform is based on a set of assumptions about scientific practice with little empirical evidence to substantiate the assumed normative goals. The pattern of thinking of science as the scientific method and teaching it as a final form process is an example that was later problematized by the social studies of science. Argumentation provides an example of how bringing scientific practices to education offers potential for new forms of learning, but such practices need to be considered in a broader context of discourse and practices if they are not to become another formulaic and largely empty characterization of science practices.

The rationale for the focus on argumentation as a pedagogical goal in science classrooms, and often as a measure of students' abilities to engage in science, is grounded in three central premises. First, argumentation offers opportunities to engage students in seemingly authentic scientific practices. The focus on engaging students in discourse practices is tied to research identifying the importance of students "talking science" and learning the genres of such discourse through participation (Kelly, 2010; Kelly & Crawford, 1997; Lemke, 1990; Roth, 2005). Second, argumentation may offer ways for students to learn the knowledge of a given discipline in a more thorough and deeply conceptual way. Student learning of scientific concepts poses a challenge for educators, as often even after instruction, central scientific concepts are not well understood. Argumentation is seen as a pattern of science discourse that leads to sense making and thus deeper conceptual understanding. Third, argumentation is often seen as a means to teach about the nature of science as a discipline. Engaging students in making evidence-based claims may foster such understandings (Kelly, 2008). We now discuss the problems embedded in each of these three premises and then discuss the limitation of a focus on argumentation both pedagogically and analytically.

Nature of Authenticity

Argumentation is a practice in science and therefore engaging science students in argumentative practices may be viewed as a reasonable method for engaging students in authentic practices of science. We generally agree with the fact that argumentation offers ways to engage students in authentic science; however, we do so with a number of caveats. What counts as an authentic process raises questions both about the actual scientific practice in question and also the educational wisdom of authenticity from a pedagogical point of view. As we have argued, scientists engage in a range of discourses to accomplish scientific work. Some of these discourses include marshaling evidence. Nevertheless, there are other ways of communicating, building affiliation, and interacting where explicit statements of claims supported by evidence are not part of the discourse. Focusing on the more formal types on discourse of a community can lead to the discourse being reduced to a list or heuristic as happened with five paragraph essay in English (another attempt to formally structure a dynamic form of argument) or the steps of the scientific method.

The other imbedded assumption in this premise that warrants examination concerns the nature of authenticity in classroom practice. It is not necessarily the case that making the discourse practices of a science classroom more like the discourse of practicing scientists leads to better science learning environments as the two sets of practices have different purposes and contextual constraints (Kelly & Brown, 2003). Authentic learning contexts may require ways of speaking, listening, writing, and so forth, that are central for learning, but not related to the work of producing new knowledge beyond a limited and local audience (McDonald & Songer, 2008).

Argumentation, spoken or written, occurs with and by real people, in situated contexts, with real and intended audiences. Thus, while attention to the substantive aspects of evidence use gives us some insights into the uses of discourse in science contexts, there will be other dimensions of language use, for other purposes, including, but not limited to, taking social positions, building alliances, saving face, and so forth. Ryu and Sandoval (2008) indicated that the amount of normative argumentation students in small groups engaged in varied across groups based on student ability. Students spent discourse time sorting through the tasks of group work or finishing the task without disagreement and had few substantive disagreements about the science where normative arguments occurred. The fact that the focus of much of the discourse was not argumentation does not mean it was not pedagogically valuable; it points to the fact that argumentation occurs with and by real people, in situated contexts, with the real and intended audiences. People are living, thinking beings, with multiple goals, many of which have nothing to do with the cognitive aspects of creating an argument, even if they need to go through the motions to accomplish tasks in a classroom.

The complexity of goals that occur in real contexts means that part of the conversation about authenticity in science classrooms must take into account that school science talk is not the same as science talk. There have been many discussions of the idea that students should be apprenticed in or acculturated to a community of science practitioners. However, this is problematic, as the classroom teacher is not an authentic participant in the community of science practitioners nor are schools context designed to produce new scientific knowledge. Students are being acculturated into classroom science learning practices. This means that it is not only actually impossible to construct authentic science classroom practices in this way, but also that it is likely not desirable, as the practices that best help students to understand science are not identical to the practices that help scientist develop new scientific understandings.

Arguing to Learn

Learning how to align evidence through verbal, written, and symbolic representation may support student learning of scientific concepts. Science learning clearly needs to include more than the "final form" science of known theory and facts (Duschl, 1990). Learning science concepts should include understanding the evidentiary basis for how concepts were derived and how and why they are used to understand the natural world. For example, knowing there is a theory of plate tectonics, and even some of the key characteristics of this theory, does not necessarily entail understanding. As noted by Duschl (2008), a thorough understanding of theory includes knowing the conceptual, epistemic, and social dimensions of the theory. Knowing the evidentiary bases for the theory, and ways that it can be applied in a variety of context, includes understanding what counts as a good argument in the relevant field. Thus, argumentation may serve a role in this type of learning, but nevertheless other learning goals and means are needed to scaffold student learning.

Argumentation can be part of a discourse-rich learning environment supporting student understanding. There is some evidence that students' conceptual understandings in science can be deepened and enriched via argumentation, although some level of experience and knowledge of the content seems critical (von Aufschnaiter et al., 2008). Much of the research around the impact of argument as a pedagogical tool has occurred in contexts where argumentation was an explicit structure of the activity. Sampson and Clark (2011), for example, asked students to evaluate different explanations of a discrepant event and then examined the quality of their written arguments. They found differences in the way that students argued based on their ability groupings and indicated more about the nature of different types of argumentation, rather than the degree to which it develops content understanding. There is also some evidence that the role of questions between peers in the context of argumentative discourse is critical to learning (Chin & Osbourne, 2010). The explicit inclusion of other discourse practices (questioning) as part of the claims/evidence/reasoning notion argumentation literature indicates there is complexity to the pedagogical enactment of argumentation as a support for learning. Such complexity is contingent on a large number of contextual factors, such as the participants' view of the purpose of the tasks, the participants' personal and interpersonal goals, the group dynamics (for the case of small group discourse), the real and intended audience, the extant knowledge drawn into the conversation, and the established norms for speaking, listening, and interacting. It seems to follow then that arguing to learn can only happen in the larger context of science sense-making discourse that occurs around and within the arguments.

Nature of Science

One more explicit description of the understandings of the practices and norms of science as a community has become characterized and studied as the nature of science. A number of scholars have argued that understanding the nature of science needs to include some experiential components (Duschl, 2008; Kelly, 2008; Sandoval & Millwood, 2005). Argumentation may be a means for students to understand the practical, conceptual, and epistemic nature of scientific practice (Duschl, 2008). Such engagement in one of the discourses of science (i.e., argumentation) will not be sufficient to develop students' views of the complexity of the nature of science. Furthermore, not all aspects of science are made evident in argumentative practices. For example, learning how to observe particular features within an observable field of vision is an important aspect to participation in science (Kelly, 2010). Coming to observe an instance of a phenomenon as seeing as a particular feature often requires more knowing others with relevant knowledge and experience making the phenomenon witnessable and recognizable to a novice observer (Goodwin, 1994).

While such forms of learning to observe require discourse, the form may not involve argumentation. Rather, rendering the phenomenon witnessable requires other forms of discourse. Through such participation, novices or students may learn how to observe from a disciplinary point of view and thus learn both aspects of the nature of science and how to establish facts to be subsequently used in arguments. It is clear that the pedagogical work of the teachers' discourse involves orders of complexity of fostering epistemic practices related to argumentation. Jiménez-Aleixandre and Reigosa (2006) indicated that the epistemic operations of a teacher include three distinct referential levels: specific examples, a class of referents, and abstract referents and exemplifies the complexity of using discourse with students as a method for developing their understanding of the nature of science, which is itself a form of discourse. Thus, to view learning the nature of science, not as stipulative definitions, but as engagement in scientific practices, entails understanding the ways that argument and other discourse forms contribute to such participation. For example, learning what counts as a "good" or "acceptable" observation may entail sense making through gesture and other representational forms among members of a epistemic community.

We now return to the examples from the chemistry classroom to consider how argumentation may contribute to our understanding of the events, and if taken as the primary lens for viewing classroom discourse, impose constraints on the ways sense is made for participants.

Return to Sense-Making Examples

Returning to the sections of classroom discourse above, we want to examine the discourse from the point of view of the argumentation that occurs. The chemical reaction and its equation are as simple as it can be: $Zn + S \rightarrow ZnS$. Yet, reviewing the transcript, the discourse cannot be easily reconstructed into an argumentative pattern. There is much discussed, but the teacher's central claim must be discerned through the clutter of naturalistic talk and action—both for us as analysts and presumably by the students in the class. Furthermore, the evidence in this case is not empirical; indeed, the teacher, drawing from a cooking analogy, is trying to set up a thought experiment so that the students first predict the most efficient ratios for the reactants, and from this lead them to devise an experiment, consider the consequences, and subsequently redesign the experiment to adjust the reactants' respective masses to adhere to the inferred chemical principle of mole ratios.

At this point, the best we can do to reconstruct the main argument is as follows:

Claim: Zn and S react in an atomic ratio of one-to-one.
Evidentiary support: the chemical equation $Zn + S \rightarrow ZnS$
Warrant: chemical equations are expressions of chemical reaction in molar ratios

Yet, in the flux of the actual discourse, and with the absence of a clear distinction between the mass and molar mass (at least at this point in the conversation), the sought conclusion is not at all obvious to the student, Casssandra, and perhaps others. The reading of the chemical equation 1 atom plus 1 atom yields one molecule and the mathematical identity of the one-tenth-to-one-tenth ratio to the one-to-one ratio seem to be the ostensive goals of the extended discussion. The teacher sought participation, asked students to explain, set up a comparison across groups, and reiterated some conclusions, and yet the pedagogical goal remained elusive. The confusion on the student's part is not an indictment of argumentation as a process—the teacher could have framed the argument more effectively and so forth. Rather, the case shows that the elaborate plan, complete with the cooking analogy, the potential for multiple experiments, and revisiting of the main ideas, is constructed both (a) in ways more complex than can be readily captured through argumentation analysis and (b) through discursive work that includes social and expressive functions of language that cannot be characterized through argumentation analysis.

It is impossible to tell if the discourse in class would have been more productive if the teacher had focused more explicitly on argument components such as claims, evidence, and warrants. The students were proposing solutions to the overall questions, the amount of sulfur needed for the reaction. These proposed solutions could be taken as claims and the teacher could have pressed for evidence and reasoning around those claims. However, the discourse that is present in these excerpts shows productive sense-making activity where both the teacher and the students are engaged with connecting their proposals with each other and with the target concepts of the phenomenon. Both pedagogically and analytically there are significant advantages to viewing this classroom activity as an engagement in science sense making rather than in argumentation.

Conclusion

By contextualizing our ideas in examples of classroom practice, we hoped to show that viewing science classrooms from an argumentation point of view can be both beneficial (in seeking a method to consider how participants use evidence) and a limitation for understanding the propositional, social, and expressive functions of language use (Cazden, 2001). While much can be said about the uses of argumentation to consider how evidence gets talked and written in science learning environments, we focused on some of the limitations of an argumentation framework, limitations that are particularly acute when argumentation is not considered in the broader contexts of everyday discourse. We conclude this chapter by discussing the analytic, pedagogic, and equity limitations present in an argumentation framework.

First, there are analytical limitations to any argumentation framework. Argumentation, as a presupposed normal goal, does not readily occur in many perfectly successful conversations, even conversations around science ideas. Conversation cooperation often entails assumptions about common understandings that go unstated—this is an efficient way to speak—and has been shown empirically in studies of classroom discourse. We will not always see argumentation in everyday life, even in science contexts of various sorts, even when evidence is readily available (Kelly et al. 1998). Even when argumentation, or at least evidence use, is employed by speakers, the methodological challenges include understanding the norms for interaction—typically constructed outside the substance of evidence use itself—within the community in question. We have argued that science includes many discourses, including importantly, sense-making conversation where persuasion is not the goal of the interaction.

Another way to consider the idea of sense making discourse is in terms of Wittgenstein's (1969) notion of language games or in terms of Gee's (2010) notion of D/discourse. While argumentation is one of the language games of science, it is not the only one, and is not even the most common one, it is simply the one that is most analytically accessible as we have given it a formal structure in terms of claim, evidence, warrant, and rebuttal (and associated uses with the rules of the language games). The discourses that construct the practices of science and learning science are many fold. Narrowing the focus to one aspect of the discourse, in large part due to its analytical accessibility, can lead to missing the forest for the trees. When arguments are used, the norms and expectations for conversation need to be considered and recognized so that attempts at persuasion are not viewed merely from the substantive content of the argument, as questions about what counts as evidence, explanation, a reasonable expectation for inferences from the audience, and other genre conventions frame how arguments can be understood by interlocutors and analysts alike.

Second, there are important pedagogic limitations of an argumentation approach. The field of science education has moved from using argumentation analysis as a research method to assess evidence to using argumentation both as a tool for analysis as well as a tool to support students' uses of evidence through instruction. This is an important development and many interesting and innovative techniques are being developed (see e.g., Erduran & Jiménez-Aleixandre, 2008). While we recognize these developments as productive with much potential, we caution that the views of classroom discourse do not become too narrow. Instruction includes more than marshaling evidence for certain concepts. Much like concept change theory that became routinized to the chagrin of some of the founders (Strike & Posner, 1992), pedagogy drawing on argumentation should be wary about becoming too mechanized.

The multifarious using of language and other symbolic systems in science alluded to earlier provide a model of open, diverse uses of language to support the multiple goals of the relevant social group. As the field develops better instructional design and research analytics, we look for the development considerations of how norms for evidence use and interpersonal communication developed over time. Argumentation may provide excellent ways to achieve cognitive, epistemic, and communicative goals called for in science education reform (Duschl, 2008). We recognize that the trifold cognitive, epistemic, and communicative goals can move instruction from a focus on achieving only the normative conceptual understanding to broader understandings of knowledge and practices of science. Argumentation is one tool that can advance pedagogy in this manner, but researchers need to examine both the supports and constraints imposed by argumentation.

One final pedagogical concern is that argumentation will become calcified in an effort to turn it into a tool for support student learning. Just as happened with the scientific method or the five-paragraph essay, there is a risk that turning analytical descriptions of argument such as claim, evidence, or warrant turns them into an empty form. Science educators have spent decades railing against the idea that something as complex and nuanced as the development of new knowledge in science could be characterized in a linear stepwise process of moving from question to conclusion. In fact, the focus on argumentation is largely the result of a focus on inquiry and other attempts to make the norms and practices of science more authentic. It would be ironic to have argumentation become the snake eating its own tail by turning classroom science discourse into a linear stepwise process of building an argument.

Finally, there are equity concerns derived from pedagogic and analytic uses of argumentation. We suggest three possible equity concerns. First, research regarding language and student identity has shown that the ways of using language in science is potentially alienating for at least some students (Brown, 2004; Carlone, 2004). Students may have ways of talking at home and in other contexts that offer opportunities to make a case, but do not adhere to the narrow requirements of what might count as a good argument in science in certain contexts. While argumentation poses the potential to expand the students' repertoire of ways of speaking and listening, it may also limit participation or differentially favor students whose everyday discourse align more closely with that of science or science teaching.

Second, there may be important gender differences about the ways students choose to engage in evidence use and assessment. Argument has a vernacular meaning suggesting disagreement and possibly consternation. Furthermore, framing evidence as a contest of better arguments may enter competition that leads less to the best analysis of facts and theory and more toward producing winners and losers. Students—particularly some female students—may find such competition less attractive than the science itself, and thus lose interest that could be otherwise fostered. In such a case, the school science practice of introducing argumentation itself could be alienating to students with interests in science.

Third, argumentation has been formulated in particular sorts of ways in science education. These forms of argumentation are framed around substantive, but relatively formal, ways of aligning evidence. There may be other ways of making sense of evidence, such as through informal reasoning and everyday reasoning that are not being considered due to the focus on argumentation. Thus, our current forms of analysis of evidence may have implicit biases derived extant argumentation theory. Maintaining an interest and analytic focus on uses of evidence broadly construed, and across multiple contexts in learners' lives, would help identify the many ways that everyday reasoning contributes to understanding.

Final Thoughts

Our argument has been that a focus on argumentation offers some potentially new and exciting ways to engage students in scientific practices. We have suggested that normative goals for science education, such as understanding concepts and developing the ability to use and assess evidence, can be enhanced through the lens of argumentation. We have made this argument with the caveat that such argumentation must be understood as one of a range of plausibly useful science discourses, and one of the many discourses of school science. What counts as evidence is often determined only after the many heterogeneous, confused, and incomplete conversations around a topic. The final form science appearing in known theories is often the work of many people over many years, occurring in ways adhering to the genres and social practices similarly constructed over time. Furthermore, learning to communicate in a highly technical genre of this sort is difficult work in any context where questions about what counts as evidence, theory, explanation, and so forth are as much as stake as the putative claim in question. These questions about what counts offer opportunities for learning and need to be part of science instruction.

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