Variation in how teachers support student critique in argumentation discussions

María González-Howard & Katherine L. McNeill

Boston College

Contact info:
María González-Howard
Lynch School of Education, Boston College
140 Commonwealth Avenue, Chestnut Hill, MA 02467
gonzaldx@bc.edu

Reference as:

González-Howard, M. & McNeill, K. L. (2017, April). *Variation in how teachers support critique in argumentation discussions.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Antonio, TX.

Variation in how teachers support student critique in argumentation discussions

Traditionally, students have held passive roles in science classrooms, interacting mainly with the teacher who disseminates uncontested facts (Krajcik, Codere, Dahsah, Bayer & Mun, 2014). Dominant discourse patterns during whole class discussions mirror this transmission-focused type of instruction (Mortimer & Scott, 2003), typically encompassing initiate-response-evaluate (Cazden, 1988; Lemke, 1990) interactions. Yet, recent standards (NGSS Lead States, 2013) contend that teachers should support students in constructing their own understandings of nature through engagement in science practices, such as argumentation. Argumentation entails students "making and supporting claims, evaluating one another's ideas, and working toward reconciling their differences" (Berland, McNeill, Pelletier & Kracjik, 2017, p. 231).

Partaking in argumentation requires that students work in coordination with peers, taking on new roles (Berland, 2011), which in turn requires alteration to classroom participation frameworks (i.e. the roles and expectations of the teacher and students, as well as the goals that drive tasks; Goffman, 1981). As such, in this study we examine how different classrooms engage in argumentation discussions. Specifically, we focus on the ways that participation frameworks around student critique are, and are not, supported, an area in need of particular attention in the literature on argumentation (Henderson, MacPherson, Osborne & Wild, 2015).

Theoretical Framework

Argumentation in Science Education

Researchers in the field of science education have different theoretical perspectives about the role of argumentation in teaching and learning. As a result, various analytical frameworks have been used to conceptualize what argumentation is and how to evaluate a classroom community's engagement in this practice (Sampson & Clark, 2008). In this work, we view argumentation as not only foundational to students' knowledge construction about the natural world, but also as a learning goal in itself (i.e., the ability to engage in this science practice). Consequently, we operationalize this practice as encompassing both structural and dialogic dimensions (Jiménez-Aleixandre & Erduran, 2008; McNeill, González-Howard, Katsh-Singer & Loper, 2016). In terms of an argument's structure, this science practice includes justifying claims using both evidence and reasoning (McNeill, Lizotte, Krajcik & Marx, 2006).

Yet, arguments are not constructed in isolation. In order for students to make sense of a topic being learned about, they ought to work in coordination with peers as they construct and revise knowledge claims (Andriessen, 2007). Thus, the dialogic dimension of this highly interactive science practice encompasses students critiquing and debating the strength of a particular claim with others, as well as the revision of claims (Ford 2012). Furthermore, Berland and Reiser (2009; 2011) contend that argumentation is informed by three interrelated goals – sensemaking, articulating, and persuading – which drive the need for students to develop an understanding of a specific natural phenomenon, explain this understandings to others, and critique peers' ideas while trying to convince others that their own understanding is the strongest. In this study we focus on the dialogic interaction of critique, which has been identified as being particularly challenging for students (Henderson et al., 2015).

Discourse Patterns and Classroom Members' Roles

Science classrooms are traditionally dominated by teacher talk (Lemke, 1990) that is motivated by the purpose of transmitting information about the natural and living world to

students (Osborne, 2014). Although teachers often encourage students to contribute during class, common discussion styles (i.e., lectures and recitations) include a rigid structure that limits the extent to which students can share differing ideas, respond to their peers' contributions, and actively make sense of natural phenomena (i.e., engage in scientific sensemaking) (Wells & Mejia Arauz, 2006). Class discussions often encompass a discourse pattern in which the teacher initiates talk by asking a question, a student responds to this question, and then the teacher evaluates and/or provides the student with feedback (initiate-response-evaluate, or IRE; Cazden, 1988). The authoritative perspective on teaching that prevails in science classrooms places students as passive recipients of previously determined facts (Scott, Mortimer & Aguilar, 2006), with the teacher as primary knower and hence the sole person capable of legitimizing students' ideas (Cornelius & Herrenkohl, 2004).

All of this is contrary to what actually happens in science. Such a view leaves out the reality of science as a messy, ongoing, social process in which scientists constantly conduct investigations and make observations to gather new data, grapple over contradicting evidence, and engage in critical debates to determine the best explanations for natural phenomena. Thus, incorporating argumentation will require intentional shifts in classroom discourse, especially since many teachers are less familiar with these instructional approaches (Windschitl, Thompson, & Braaten, 2011). As such, it is important that we begin to develop a stronger understanding of what argumentation discourse patterns might look like and the roles teachers and students play in those discourse patterns in order to better support classrooms in making and sustaining these changes. Consequently, in this study we examine interactional patterns around critique during whole class argumentation discussions, as well as the interactional moves that support students in critically evaluating their peers' arguments.

Methodology

Curricular Context

This study took place in the context of teachers piloting one of two middle school science curricular units focused on argumentation; these units were titled *Plate Tectonics* (Regents of the University of California, 2012) and *Metabolism* (Regents of the University of California, 2013). Each unit concluded with a science seminar, an argumentation activity where students orally debate explanations to a question. Specifically, the question debated during the *Plate Tectonics* science seminar was – How will the Indian Plate be different in 50 millions years? Meanwhile, the question that guided the *Metabolism* seminar was – When a person trains to become an athlete, how does her body change to become better at releasing energy? To ground each discussion, students analyzed data pertaining to each seminar's question (e.g., a map of the Indian Plan with information about its surrounding plate boundaries; and data from studies about bodies' responses to exercise). During the science seminars, students were set up into two concentric semi-circles, and the inner group debated the question while the outer group observed and took notes. Halfway through the activity, the two groups switched roles. Throughout, students were responsible for driving the argumentation discussion, listening and responding to one another as they debated the question of interest.

Participants

For this study, participating teachers, Ms. Ransom and Ms. Allen (all names are pseudonyms), and their students, were selected from part of a larger project (McNeill, González-Howard, Katsh-Singer, & Loper, in press; McNeill, Marco-Bujosa, González-Howard & Loper,

2016) in which teachers piloted one of the two units previously described. These teachers had various backgrounds. For example, Ms. Ransom had over 20 years of experience and Ms. Allen was a first year teacher. Additionally, Ms. Ransom taught science to numerous classes throughout the school day, while Ms. Allen taught one class of students across every subject area (i.e., math, writing, science, and social studies). Further, as illustrated in Table 1, these teachers had a range of teaching credentials and educational experiences.

Table 1: Teacher backgrounds

Teacher	Type of Teaching Credential	Highest Level of Education	Years of Teaching Experience	Classes Taught
Ms. Ransom	Middle school or secondary science	MA	20 or more	Science
Ms. Allen	Multi-subject (elementary)	BA	1	All Subjects

These teachers also taught in different school contexts (see Table 2). While both of the schools were public, there was variation in terms of student demographics of the schools. For instance, compared to Ms. Ransom, Ms. Allen's school had larger percentages of non-White students, English-learning students, and students receiving free and reduced-price lunch.

Table 2: School and classroom context

Teacher	Unit Piloted	Grade of Students in Field Trial	Avg. Class Size	% Free and Reduced Lunch	% Non-White Students	% ELL Students
Ms. Ransom	*Metabolism*	7^{th}	21-25	< 25	< 25	< 25
Ms. Allen	*Plate Tectonics*	6^{th}	26-30	50-75	50-75	25-50

Data Source

The data for this study included transcripts of each classroom's science seminars. Recall that students were split into two groups during the activity: the inner group (i.e., Group 1) who debated the question first, and the outer group (i.e., Group 2) who engaged in the argumentation task second. Because of our interest in examining student critique, only three of these groups' seminar transcripts were included in the analysis due to their conversation including higher amounts of critique: Ms. Ransom's Group 2 (38.4%), Ms. Allen's Group 1 (29.7%) and Ms. Allen's Group 2 (21.9%). The first group's discussion in Ms. Ransom's class was not included because individuals less frequently engaged in the dialogic interaction of interest (7.5% of the discussion included critique). Thus, there was little to analyze in terms of how student critique was supported during the science seminar activity. We will say more about how the argumentation discussions were coded for critique in the following section.

Data Analysis

The science seminar transcripts were analyzed using an exploratory sequential design (Creswell, Clark, Gutmann, & Hanson, 2003), which is well suited for deeply exploring complex phenomena (Creswell, 1999). Specifically, we first used social network analysis (SNA) to shed light on the interactional patterns around critique in each science seminar. We then employed

discourse analysis (DA) to better understand the circumstances that engendered student critique during the argumentation discussions.

Conducting the social network analysis. SNA offers a means by which to map interactions between actors in a network (such as the teacher and students in a classroom), visualizing and quantifying certain characteristics of these interactions (Carolan, 2014). Specifically, we operationalized and examined "critique ties" between classroom members. To conduct the SNA, we first broke each science seminar transcript into utterances (i.e. a unique idea or contribution). We achieved 94.7% reliability in this task. Next, two raters independently coded 20% of each transcript for instances of critique (defined as utterances that included disagreement or an evaluation of some aspect of the discussion, such as "the evidence does not support that claim"), obtaining 82.3% inter-rater reliability. Any coding disagreements that arose were resolved through discussion. We then determined the ties between turns of talk that entailed critique (i.e., who was critiquing whom?). Again, two raters independently coded 20% of each science seminar transcript in terms of ties and achieved 87.6% inter-rater reliability. Finally, using all of the coded data, we created valued, directed matrices. The term "valued" refers to the extent to which a tie between two actors did or did not exist (i.e., 0 = no critiquing utterances made toward a person, 7 = 7 critiquing utterances made toward a person), while "directed" refers to whether or not a critique was reciprocated. The dimensions of each matrix included the students in a group and the teacher, with each actor represented by both a row and column. The matrices were used to conduct the SNA with UCINET 6 software (Borgatti, Everett & Freeman, 2006). This software includes NetDraw, a visualization tool that creates sociograms, which we used to examine the interactional patterns for critique across the seminars. Please see González-Howard and McNeill's (2016) work for a detailed account of how the SNA was conducted.

Conducting the discourse analysis. The underlying idea of DA is that people use language to *do* things (Potter & Wetherell, 1987), but that language use does not occur in isolation. For this analysis, we were particularly interested in how language was used to encourage instances of student critique. Specifically, investigating interactional moves provided insight into how individuals were positioned in alignment, or in opposition with one another (O'Conner & Michaels, 1993). This was necessary to consider within the context of a science seminar, as during the debate students were meant to notice similarities and differences between contributions, to critique differences, and to build upon previous ideas. For the DA, the science seminar transcripts included detailed information about the conversation. Table 3 includes the transcription conventions described by Atkinson and Heritage (1984) that we used to explore the sequences of turns around student critique. These particular conventions were important to include because they correspond to common occurrences during large group debates, such as people speaking over one another, or an individual speaking loudly to sound more persuasive. Further, certain conventions, such as (), were included to account for the realities of transcribing (it can be difficult to correctly hear all contributions during a video recording of a conversation).

We read each transcript multiple times, looking around the instances that exemplified the phenomenon of interest (i.e., student critique). Readings of the text were guided by questions that enabled us to better understand the interactional moves that helped create circumstances in which students engaged in critique (e.g., Are only the teachers prompting for critique or are the students also involved in this process? Does an individual need to engage in critique in order to prompt another to do the same?) We used analyzable features of the argumentation discussion to answer these questions, including the markers described in Table 3. We then grouped extracts that followed similar patterns, and used analytic memoing (Miles & Huberman, 1994) to track our

thought processes. This analysis resulted in the identification of four interactional moves – two conducted by one teacher, Ms. Allen, and the other two conducted by students across the three focal seminars – that stimulated student engagement in critique.

Table 3: Transcription conventions (adapted from Atkinson & Heritage 1984)

Convention	Meaning
-	A hyphen after a word or part of a word indicates a cutoff or self-interruption
.	Period indicates falling, or final, intonation, not necessarily the end of a sentence
?	Question mark indicates rising intonation, not necessarily a question
:::	Colons indicate stretching of a proceeding sound, proportional to the number of colons
word	Underlining indicates some form of stress or emphasis on underlined item
WORD	Uppercase indicates loudness
°word°	Degree signs indicate whispered speech
<word>	Speeding up
>word<	Slowing down
(( ))	Double parentheses enclose descriptions of conduct
[	Separate left square brackets, one above the other on two successive lines with utterances by different speakers, indicates a point of overlap onset
]	Separate right square brackets, one above the other on two successive lines with utterances by different speakers, indicates a point of overlap ending
(#)	Number(s) in parenthesis indicate silence in tenths of a second
(.)	A dot in parenthesis indicates a "micropause," hearable but not readily measureable; ordinarily less than 2/10 of a second
( )	Empty parentheses indicate that something is being said, but is inaudible
(…)	Indicates that several turns of talk have elapsed
word	Bolded words indicate critique

Findings

This section is organized to examine the teacher and student interactional moves that created circumstances under which students evaluated and/or disagreed with other students' ideas during the science seminar. To ground these results, we first present and discuss the sociograms of critique that emerged from the three focal groups' science seminars. These sociograms offer insight into which classroom members engaged in critique, and how (i.e., who were students directing their critiquing remarks towards?). Afterwards, we describe four interactional moves that stimulated student critique during the science seminar activity. We present these interactional moves one by one – starting with those carried out by the teacher, and then with those performed by students – illustrating each interactional move through excerpts from the three groups' argumentation discussions.

Sociograms of Critique

Throughout the three focal groups' science seminars, there were several instances of students critiquing the ideas presented by others. As noted earlier, the percentage of utterances coded as "Critique" was 38.4% for Ms. Ransom's Group 2, 29.7% for Ms. Allen's Group 1, and 21.9% for Ms. Allen's Group 2.

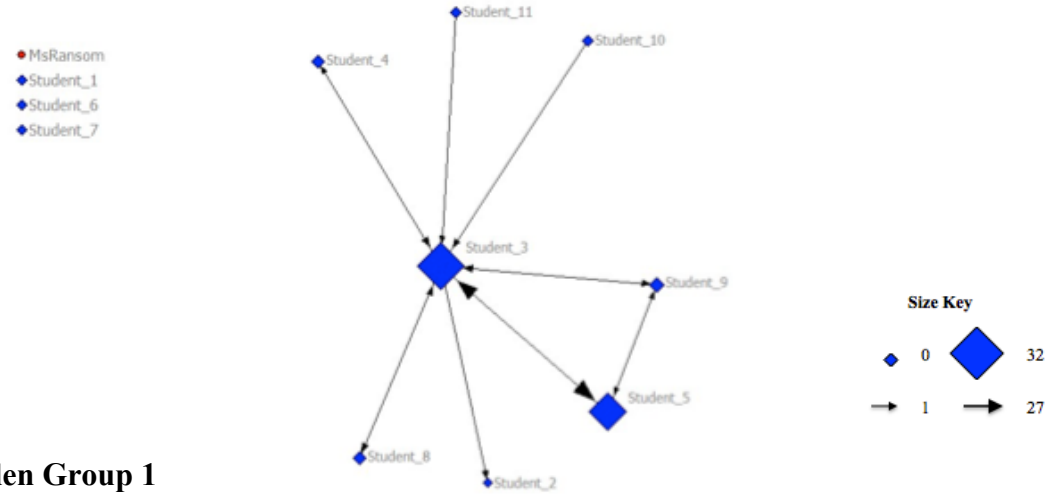
The sociograms in Figure 1 illustrate the interactional patterns around critique in these groups' seminars. Note that there were individuals in all of these groups who did not make an utterance containing critique, nor were they the recipients of such an utterance; these "benched" actors are listed to the left of each sociogram. In Ms. Ransom's class, benched individuals included 4 out of 12 people (33%) in the group. A larger percentage of classroom members in Ms. Allen's class did not partake in critique – 9 out of 15 (60%) from Group 1, and 8 out of 14 (57%) from Group 2. Across both classrooms, Ms. Ransom and Ms. Allen's names are included in these lists, meaning the teachers did not evaluate nor dispute any student's contribution during the science seminar. However, as described later, this is not to say the teachers were uninvolved in creating circumstances that enabled and stimulated critique during the discussions.

Across the three seminars, a few classroom members are prominent in terms of producing critique, evidenced by the larger size of their nodes (i.e., the blue diamonds = students, and the red circle = teacher). Specifically, these individuals include Students 3 and 5 from Ms. Ransom's Group 2 (with 32 and 24 utterances), Students 2, 1 and 6 from Ms. Allen's Group 1 (with 24, 19 and 10 utterances respectively), and from Ms. Allen's Group 2, Students 10, 13, 3 and 14 (having made 20, 14, 11, and 9 critiquing utterances, in that order). Relatedly, the ties in the sociograms (i.e., the arrows between the actors) offer insight into not only who produced critiquing ties, but also who was the recipient of them. In all three seminars there was one individual who not only critiqued often, but also frequently received critique from various other students. Specifically, these individuals were Student 3 in Ms. Ransom's Group 2, Student 2 in Ms. Allen's Group 1, and Student 10 in Ms. Allen's Group 2.

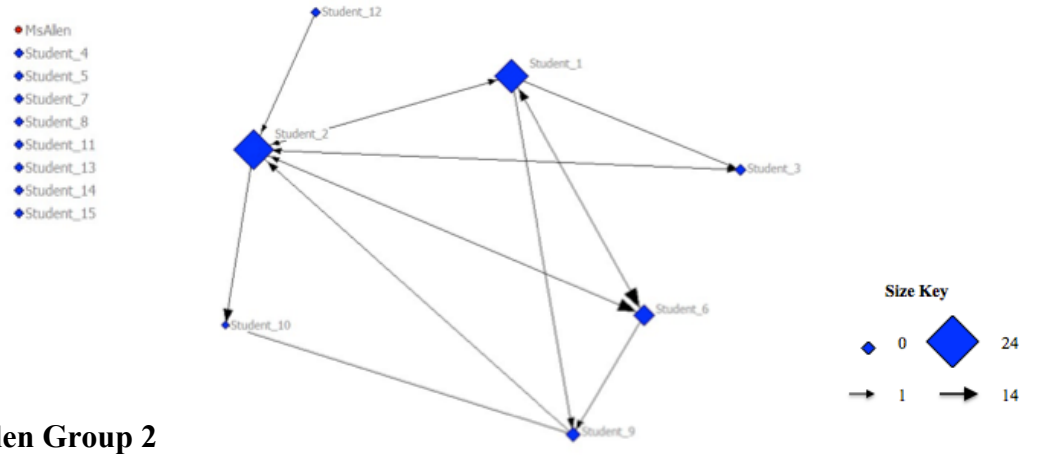
During the argumentation discussions in Ms. Allen's class, there were more instances of students with critiquing ties to multiple peers (e.g., in Group 1, Student 6 had critiquing ties with three peers: Students 1, 2 and 9), while in Ms. Ransom's class most students had a critiquing tie to only one other student (e.g., Student 10 had a tie with Student 3). Additionally, the size of the arrowheads in the sociograms indicate that in Ms. Ransom's group students sent critiquing ties at higher frequencies in comparison to the groups in Ms. Allen's class (see keys in Figure 6.1). For instance, in Ms. Ransom's class, Student 3 directed 27 critique utterances at Student 5, while the largest number of critiquing utterances directed at another student in Ms. Allen's Group 1 was 14 (from Student 1 to Student 6).

Overall, these sociograms highlight the ways that interactional patterns around critique were alike and unlike one another across the focal groups' science seminars. Although informative, and useful for identifying key individuals that engaged in this dialogic action, the sociograms do not provide details about the circumstances throughout the argumentation discussion that may have encouraged critique. For this information, we re-analyzed the science seminar transcripts using discourse analysis, which is a method for studying what people *do* with language (Gee, 2005). Specifically, this analytic approach allowed us to more deeply examine the interactional moves that took place around instances of student critique.

Ms. Ransom Group 2



Ms. Allen Group 1



Ms. Allen Group 2

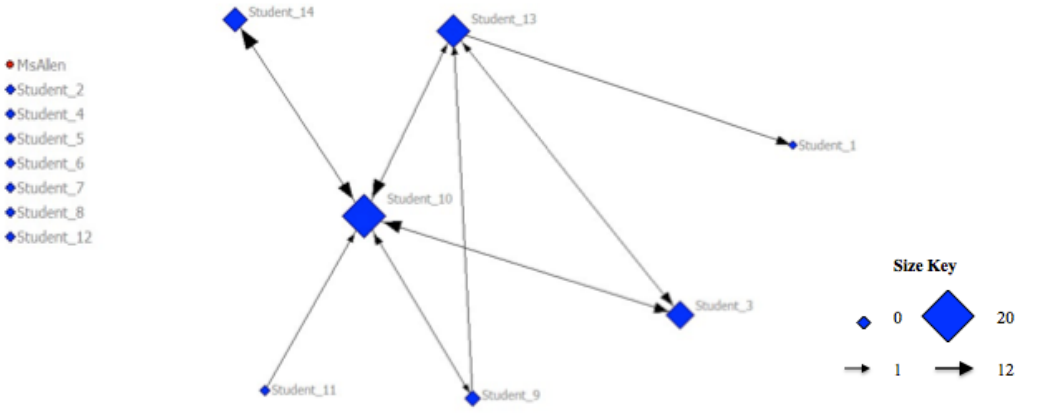


Figure 1: Sociograms of critique in the focal seminars

Interactional Moves Around Critique

In this section we describe the findings from the discourse analysis, which focused on identifying and examining the interactional moves that prompted critique during the focal groups' science seminars. Though across Ms. Allen and Ms. Ransom's classrooms both the teacher and students made moves that stimulated critique, the types of moves they made differed (see Table 4). The analysis revealed that these moves served various functions, all of which created circumstances that resulted in students critiquing their peers' arguments.

Table 4: Interactional moves that engendered critique

Interactional Move		Function(s)
Made by the teacher	Clarified or repeated a student's argument	• Distanced the argument from its author • Created space for students to think about their arguments in relation to those of their peers
	Normalized critique of other students' ideas	• Encouraged interactions amongst students • Set parameters that reminded students that they should be agreeing and disagreeing with their peers during argumentation discussions
Made by students	Made a challenging statement	• Positioned certain ideas as unreasonable and hence disputable, inviting a response
	Listed points of disagreement	• Opened up multiple avenues for the conversation to follow • Enabled student critique to be sustained

We now present and discuss these interactional moves and their functions, illustrating each through excerpts from the various seminars. While the transcription conventions used to conduct and represent the discourse analysis are described in the Methodology section, it is worth noting that the bolded words in the excerpts correspond to utterances previously coded as "Critique." It is helpful to know where the critiquing utterances occurred in order to understand how they were engendered by particular interactional moves.

Interactional moves made by the teacher. The interactional moves that we describe in this section were only carried out by one of the focal teachers, Ms. Allen, who spoke many times during her students' seminars. Ms. Ransom, on the other hand, remained quiet throughout the argumentation activity. Although Ms. Ransom's silence could also be considered productive for her students' seminars (as it sent the message that students were in charge, and that what they were doing was appropriate), we focus on the audible language moves classroom members made that encouraged student critique. Thus, examples for each of the following teacher interactional moves will be only from Ms. Allen's class.

Moreover, the two interactional moves discussed in this section are different ways by which Ms. Allen conveyed to her students the *definition of the situation*; a notion by Goffman (1959) that describes how social situations are informed by the interactional expectations that individuals persuade one another are important. In the case of the science seminar activity, Ms.

Allen went to great lengths to convey the definition of the situation as a debate amongst students, in which critique was instrumental.

Clarified or repeated a student's argument. One of the interactional moves that prompted critique, which Ms. Allen often performed during the science seminar activity, was clarifying or repeating a student's contribution. The data suggests that this interactional move served two functions during the argumentation discussions: 1) the move distanced the argument from its author, and 2) it created a space for students to think about their argument in relation to the one just presented. In the excerpts that follow we highlight instances where Ms. Allen carried out this interactional move. Recall that her students analyzed a map containing information about various plate tectonics, and that they were debating the question – How will the Indian Plate be different in 50 million years?

The following excerpt is from Group 1's science seminar. In Line 5, Ms. Allen uses her turn to ask Student 9 to clarify his argument ("Indi- the Indian Plate will go where?"). After Student 9 does so, the teacher repeats his claim, slowing the tempo of her speech and moving her hand over a projection of the map, offering a visual representation of the claim (Line 7). These "contextualization cues" (Gumperz, 1992) function to highlight the ideas noted by Student 9, and to present them for further analysis. Subsequently, in Line 8, Student 6 disagrees with his peer's argument, proposing a different claim ("°**No::° isn't it North<u>west</u>**?").

Excerpt 1

1	Student 9:	((reads from notebook on lap)) I think that India will uh:: (.5) go east (.) eastward uh closer to North America (.) uh in fifty million years
2	(2.5)	
3	Ms. Allen:	Okay (.) let me clarify his argument.
4	(1)	((Ms. Allen gets up and walks to a projection of the map))
5	Ms. Allen:	Indi- the Indian Plate will go where?
6	Student 9:	((moving hand in air to the right)) East Northeast
7	Ms. Allen:	>Northeast ((moves hand to the right on map))< in fifty million years
8	Student 6:	°**No::° isn't it North<u>west</u>**?
9	Student 9:	Yeah
10	Student 3:	°Does anybody [agree] or disagree?°
11	Student 9:	[Yeah Northwest]
12	Ms. Allen:	Northwest >Northwest<
13	Student 3:	Okay (.) Student 1
14	Student 1:	**I disagree with Student 9 because** ((moving hand in air)) **I don't exactly think it's gonna** (.) **keep going up northwest**. **I think it's gonna go past** (.) **not just stop there**. **So:: I disagree with him**.

Once students settle on the revised claim, Ms. Allen reiterates the new idea twice, slowing down her speech to highlight the new argument being presented (Line 12). Again this interactional move serves to allow students to think about how the new claim relates to their own, and opens up the discussion for students to dispute the new idea being proposed. Furthermore, this move helps decontextualize the claim being made from its original author, which might support

students in subsequently critiquing the new idea. As such, Student 14 then enters the science seminar, articulating her disagreement with the current claim (Line 14).

A similar sequence of events is presented in Excerpt 2, which occurred during the second group's argumentation discussion in Ms. Allen's class. In Line 3, the teacher repeats a piece of evidence that Student 10 just brought up to support her claim ("Oh in *The History of Earth*."). Then, Ms. Allen questions Student 9, placing stress on the word "you're," which emphasizes that the idea she is reiterating is Student 9's. Similar to the previous excerpt, Ms. Allen again slows the tempo of her speech, which serves to clarify the difference between different arguments ("You're saying you think it would move >faster< than fifty million? Or (.5) [slower?]"). This interactional move works to contrast Student 10's argument with the idea presented by Student 9. In Line 4, Student 9 then disputes Student 10's idea ("[**No**.] **I mean like- it's slow- it would take** (.) **a** (.) **longer amount of time**"), which Ms. Allen repeats in Line 5 ("Longer than fifty million years to get there"), again placing stress on the area of contention between the students.

Excerpt 2

1	Student 9:	**How would it move that fast in fifty million years**?
2	Student 10:	Because it moved that- it moved like that in (.) *The History of Earth*
3	Ms. Allen:	Oh in *The History of Earth*. ((looking at Student 9)) You're saying you think it would move >faster< than fifty million? Or (.5) [slower?]
4	Student 9:	[**No**.] **I mean like- it's slow- it would take** (.) **a** (.) **longer amount of time**
5	Ms. Allen:	Longer than fifty million years to get there
6	Student 10:	**Yeah but** (.5) **fifty million years i::s pretty long**
7	Ms. Allen:	((looks at Student 9)) So Student 9 you >agree however< (.5) you think it'd be longer than fifty million?
8	(.5)	((Student 9 nods))
9	Ms. Allen:	Okay. He agrees with the theory but (.) he just thinks the time frame would be longer (.5) okay
10	Student 13:	**°Um I disagree° because I don't think that the Eurasian Plate could** (.) **just go here:: when there's also the big Pacific Plate right here**.

Afterwards, Student 10 continues to refute the claim presented by Student 9 ("**Yeah but** (.5) **fifty million years i::s pretty long**"). The teacher's contributions during this interaction involve her repeating student ideas, as well as emphasizing or lengthening particular elements of the argument. These moves function to clarify the difference between the students' arguments, shedding light on the area where their ideas continue to contrast (e.g., in Line 7 Ms. Allen says, "So Student 9 you >agree however< (.5) you think it'd be longer than fifty million?"). In the subsequent turn (Line 10), Student 13 disagrees with his peers' ideas.

Normalized critique of other students' ideas. Another interactional move made by Ms. Allen during the science seminars was asking her students a question that implicitly normalized critique. Specifically, following a student's contribution, the teacher would prompt students to voice how their arguments compared to that of their peers. As seen in the excerpts that follow, this particular move served to 1) encourage interaction amongst students, and 2) set parameters that reminded students that they should be agreeing and disagreeing with their peers during the argumentation discussion.

The following excerpt took place during Group 1's seminar. In Line 2, Ms. Allen uses her turn to prompt students to react to Student 2's argument ("Okay (.5) now next person to say I >agree< or I >disagree< because?"). The manner in which the teacher frames her question during this turn not only encourages students to interact with their peer, but also provides them with the language with which to do so. Moreover, Ms. Allen slows her speech to focus on the two ways that students can respond, placing emphasis on the different opinions (i.e., agreement or disagreement). In Line 4, Student 9 disputes Student 2's argument, using the frame the teacher previously offered ("**I disagree because** (.) **a plate can't go over another plate without it subducting**..."). In Line 6 Ms. Allen again encourages students to respond to their peer's idea, providing the same conversational sentence starter as before ("[Anyone] wanna start off with >I agree with that because::< or I disagree?").

Excerpt 3

1	Student 2:	It would go up over Africa and past Asia
2	Ms. Allen:	Okay (.5) now next person to say I >agree< or I >disagree< because?
3	Student 3:	Okay (.) Student 9
4	Student 9:	**I disagree because** (.) **a plate can't go over another plate without it subducting** (.5) **uh:: because they- <right now they're just pushing up against each other> and making mountains. But** (.) **I don't think a plate can go over another plate unless it subducts**
5	Student 12:	**So it really can't [go over-]**
6	Ms. Allen:	[Anyone] wanna start off with >I agree with that because::< or I disagree?

Not only did this interactional move bid for student contributions – specifically, contributions in which students would respond to their peers' ideas – but, by including the frame of "I disagree because," it also gave students permission to dispute those ideas, an interaction that is not common during more typical whole class discussions (e.g., IRE).

The same interactional move can be seen in Excerpt 4, which took place during the first group's seminar, about five minutes after the occurrence captured in the previous excerpt. After a few moments of silence following a student's contribution, the teacher turns to Student 6 and encourages him to respond to Student 2, who had just disagreed with his argument (Line 3). Attending to Student 6's apparent discomfort with the situation, evidenced by his whispered speech ("°I think we have a disagreement here°"), Ms. Allen then articulates two potential avenues Student 6 can take in his response ("Do you might- do you >agree or disagree<?"). This interactional move functioned to remind students that conventions for the science seminar activity allowed them to contest their peers' arguments. In Line 6, Student 6 answers his peer's question, appealing to agreement, although his response indicates that he continues to believe a different claim is viable. However, two other students then more openly articulate their dissent (e.g., in Line 8 Student 2 says, "**It's been like** (.) **I don't see how it would change now**").

Although Ms. Allen was predominantly observed enacting this interactional move, there were also a few instances during which the "discussion leader" also performed this move. The discussion leader was a student appointed by the teacher to direct the conversation, who was responsible for calling on students to speak during the seminar. An example of such an instance can be seen in Excerpt 1 in Line 10. Here, Student 3 employs the same language used by the teacher previously in the seminar ("°Does anybody [agree] or disagree?°").

Excerpt 4

1	Student 2:	**It's been going Northeast the whole time and making like a collision zone** (.5) **I- I mean Student 6 says it's <all of a sudden> gonna be a transform or something** (.) **it's gone collision this whole time** (.) **why would it change <u>now</u>**?
2	(3.5)	
3	Ms. Allen:	((looking at Student 6)) Do you have anything to say?
4	Student 6:	°I think we have a disagreement here°
5	Ms. Allen:	((looking at Student 6)) Do you might- do you >agree or disagree<?
6	Student 6:	Well:: (1.5) it's always <u>been</u> going up (.) so sometimes it could happen (1.5) like it might go down (.) it might to up. Sometimes we don't know what happens but (.) I usually agree
7	Student 3:	Student 2 then Student 1
8	Student 2:	**It's been like** (.) **I don't see how it would change now**. [**That's-**]
9	Student 1:	[Umm yeah] it's been going up and it <u>will</u> probably go up **but** (.5) **what do you mean >it's gonna go down**?< **It's been going up for the past like five hundred- six hundred million years what makes you think it's gonna go down so like in fifty million years**?

However, unlike the teacher, Student 3 whispered this remark, possibly capturing hesitancy or discomfort in carrying out a role typically reserved for the teacher during classroom discussions. Nonetheless, it is interesting to point out how this student, who had been assigned a pseudo-teacher role during the argumentation activity, began taking on this interactional move, which subsequently engendered student critique. Across both of these interactional moves it is worth noting that none of Ms. Allen's comments were actually coded as critique, yet they enabled students to engage in this dialogic move. Additionally, in many of the example excerpts the teacher's slowed pace of speech served as contextualization cues (Gumperz, 1992) to highlight differences in arguments being made.

Interactional moves made by the students. The teacher was not the only classroom member responsible for carrying out interactional moves that stimulated student critique during the focal science seminars. Across all of these groups' discussions, students also made particular moves that encouraged the critical evaluation of an argument put forth by a peer. This is unlike the teacher moves, which were only prevalent in Ms. Allen's classroom. In this subsection we present and describe two interactional moves students made during the activity that prompted critique. The two interactional moves discussed in this section include the ways by which particular students made assessment – or the critical evaluation of another's ideas – relevant (Pomerantz, 1994) to the argumentation discussion.

Made a challenging statement. Throughout the argumentation discussions, critique was engendered when a student's interactional move functioned to invite another student's response, by positioning certain ideas as unreasonable, and consequently disputable. We refer to these moves as "challenging statements."

Excerpt 5 is from Group 2's seminar in Ms. Ransom's classroom. Recall that her students analyzed results from different studies that compared information about athletes and non-athletes (e.g., the amount of blood the heart pumps in one minute), and that they were debating the question – *When a person trains to become an athlete, how does her body change to become*

better at releasing energy? In Line 4, Student 3 responds to students who had expressed why they believed the data from the studies were reliable. In his response, Student 3 repeats his peers' language ("**They probably wouldn't**"); his emphasis on the word "probably" functioned to highlight an alternative possibility. Student 3 then follows this remark with, "**but** (.) **maybe the scientists want to give misleading data**," stressing the word "want," a move that served to place doubt on the intention of the scientists who gathered the data.

Excerpt 5

1	Student 9:	**Like it's probably made so** (.) **well like- they probably** (.) **they kinda implied that they don't have** (.) **like any medical** [**conditions**]
2	Student 8:	[**They probably**] **would- they probably wouldn't be eligible if they had some any kind of medical** [**condition**]
3	Student 5:	[**Yes** (.) **yeah**] ((turns to face Student 3)) **They they they they probably** () **chose people that** [**had the same-**]
4	Student 3:	[**They probably wouldn't**] (.5) **but** (.) **maybe the scientists want to give misleading data** (.) <**and I think** [**that-**]>
5	Student 5:	[The wait] (.5) what? ((laughing)) WHY WOULD THEY DO THAT?
6	Student 3:	>**It might be misleading data.<**
7	Student 5:	((facing Student 3) **They wouldn't wanna do that because they probably took a group of people** (.) **that** (.5) ((glances quickly at notebook)) **had the same medical con- conditions** (.) >**same age** (.) **same height** (.) **same weight**<
8	Student 3:	((facing Student 5)) **I would have to disagree completely because IF THERE ARE SIX PAIRS OF TWINS then each twins' chances are they're gonna have completely different life-**
9	Student 5:	[**Yeah so they would've looked for twins that would uh like close to each other**]
10	Student 3:	[**lifestyles. So one might be a really good soccer player and one might be a**] couch potato

After Student 5 reacts to this statement by laughing and responding incredulously ("[The wait] (.5) what? ((laughing)) WHY WOULD THEY DO THAT?"), in Line 6, Student 3 repeats his idea in a slower tempo (">**It might be misleading data.<**"). This move positions the notion of the data being unreliable as likely, and subsequently worth evaluating through further discussion. As such, Student 5 critiques Student 3's argument, and the two students continue disputing the validity of the data (Lines 7-10).

The "challenging statement" interactional move is also exemplified in Excerpt 6, which is from the second group's science seminar in Ms. Allen's class (during which students debated - *How will the Indian Plate be different in 50 million years?*). In Line 2, Student 10 responds to her peer's argument concerning the movement of the Himalayan Mountains ("**But they're** (.) **but they're both** ((converging right and left hand)) **Eurasian and India**. **How will it just go like this**? ((rapidly moves hands together in air to the right))"). Student 10's emphasis on the words "just go" and "this" functioned to make the idea of the plates moving in a particular direction (taking the Himalayan Mountains with them) sound unreasonable. The quick

movement of Student 10's hands in the air served to further point to the unlikelihood of this event and to trigger a response from her peer. Subsequently in Line 3, Student 14 disagrees, explaining why his claim is probable. After a few turns of talk, Student 3 enters the conversation. At Line 10, she too employs the "challenging statement" interactional move in her re-articulation of Student 10's claim (">but< I also see how Student 14 doesn't see how that would work because India can't just slide out and go across (.) it would [kind of have to-]"), placing stress on the words "just slide out." Similar to Line 2, emphasizing these words functioned to position an idea (in this case, the manner by which the tectonic plates could move) as unlikely. This move consequently provoked a critiquing response from Student 10 (Line 11). Both of these examples illustrate the ways that students challenged their peers' ideas, using language to make an opposing argument sound unreasonable and hence disputable.

Excerpt 6

1	Student 14:	I think it (.) I think it would take the Himalayas with it because it's already on the Eurasian Plate.
2	Student 10:	**But they're** (.) **but they're both** ((converging right and left hand)) **Eurasian and India**. **How will it just go like this**? ((moves hands together in air to the right))
3	Student 14:	**Well:: if they made the Himalayas** (.) **aren't they like** (.) **forming over each other**? (.5) **So aren't they like basically connected**? [**Like subduction zone**?]
4	Student 10:	[**But the- but I don't think they are because >they're both different<** (.) **they're a plate** (.) **they're <a tectonic plate is::> they're different**. **They're like puzzle pieces** (.) **they're different so:: I don't get how you can- how can** (.) **how can it just go like this**? **Just taking the Himalayas**?
5	Student 11:	**°But they don't all connect like** [**puzzle pieces**]**°**
6	Student 14:	[Like half] of the Himalayas?
7	(3.5)	((students laugh))
8	Student 3:	So:: I I'm not choosing sides bu::t [I'm kinda going-]
9	Student 14:	[No. You have to choose sides.]
10	Student 3:	But <I'm kinda going from both sides> (.) I see where Student 10 thinks that it can go over here (.5) >but< I also see how Student 14 doesn't see how that would work because India can't just slide out and go across (.) it would [kind of have to-]
11	Student 10	[**I'm not saying that**.]

Listed points of disagreement. Finally, students were prompted to engage in critique when a peer described numerous ideas with which they disagreed. The data revealed that this interactional move served two functions during the argumentation discussions: it 1) opened up multiple avenues for the conversation to follow, and 2) enabled student critique to be sustained.

This interactional move is captured in Excerpt 7 from the science seminar in Ms. Ransom's classroom (during which students discussed the question about how an athlete's body changes during training). In Line 4, Student 3 enters the conversation, articulating the four issues that he has with the data from one study (e.g., "**Okay <one reason** (.) **is the data doesn't show the lifestyle of the twins and that could greatly impact the results of the test.**").

Excerpt 7

1	(2)	((Student 3 stands up from his seat, walks to the front of the inner circle, and turns to face his peers))
2	Student 3:	((reading from notebook**)) I think Test One** (.) **Study One is a load of bogus**.
3	(1.5)	((students laugh))
4	Student 3:	Okay (1) the reason for that (1.5) <well (.) I have multiple reasons for that> (.) ((reading from notebook)) **Okay <one reason** (.) **is the data doesn't show the lifestyle of the twins and that could greatly impact the results of the test. Two** (.) **the data doesn't show whether or no the twins have medical conditions that could greatly impact the results of the test. And above all** (.) **test number one was conducted before the twins were subjected to their exercise routines** (.) **so it is invalid to examine the way an athlete's body changes because the twins hadn't become**> ((puts notebook down; finger quotes)) **athletes yet.** ((walks back to seat in inner circle))
5	Student 5:	[**I disagree with that**] **because-**
6	Student 11:	[**I disagree with that.]**
7	(4)	(…)
8	Student 5:	((facing Student 3)) **Because it says like** (.) **so what I think like this text is saying** (.) **is that like** ((checks notebook)) **the Twin A already before they conducted the test** (.) **they were already working out three hours per week** (1) **and the** ((checks notebook)) **Twin B was already having twelve hours um:: of exercise per week**. so:: I think ()
9	Student 3:	((facing Student 5)) **I don't- I don't think that's true because it sa::ys that** ((reading from notebook)) (.5) <**scientists tested every person in the study in the same way at the beginning of the study**> ((looks up at Student 5)) **which means before they were subjected to their exercise** [**schedules**]
10	Student 5:	[**Well] you exactly proved yourself wrong** ((laughs)) **because they could have just um:: done the** (.5) **three hours per week of um:: athle- of training before they start- even started the** [**test**]
11	Student 3:	[**But**] **three hours a week isn't exactly athletic**
12	Student 9:	[**It's not athletic**.]
13	Student 5:	[**Then it's doing a sport**] (.) whatever (.) same thing
14	Student 3:	**Yeah but if they're doing a sport** (.5) **they're gonna do more than three hours a** [**week]**
15	Student 4:	[**You don't**] **know that** ()
16	Student 8:	Well (.) another way wait (.) <whoa whoa whoa whoa> WAIT. Wait you have to ((looks at Student 5)) excuse you. (.5) **Because the results of the test can-** (.5) **because it says** ((reading from notebook)) **that <the results of the test can change depending on how hard the person tries to excel** (.) **how well they follow directions** (.) **or if they're tired**.> **So:: it's not a very reliable** [**test**]
17	Student 3:	[**And**] **there are also too many variables like** (.5) **age** (.) **well I mean <I guess they're all female twins> so:: gender no. But** (.) ((raising one finger after each point made)) **medical conditions** (.) **determination** (.) **how well they-**

During this turn, Student 3 uses sequential language (e.g., "**one reason**" "**Two**" and "**above all**") to organize and present his argument, which served to clearly order the points that other students could then rebut. In addition to the three reasons listed in Line 4, Student 3 also uses air quotes around the word "athletes," a move that functioned to identify yet another area of contention. These assessments from Student 3 subsequently invite further assessments (Pomerantz, 1994). A few students state their disagreement with Student 3 (Lines 5-6). In Line 7, Student 5 disputes the third idea that Student 3 had mentioned, using the text from the data to substantiate his argument. Student 3 too uses the text to support his critique, placing stress on particular phrases ("**I don't- I don't think that's true because it sa::ys that** ((reading from notebook)) (.5) <**scientists tested every person in the study in the same way <u>at the beginning of the study</u>**> ((looks up at Student 5)) **which means <u>before</u> they were subjected to their exercise** [**schedules**]"). However, when Student 5 continues to evaluate Student 3's idea (Line 10), Student 3 weaves into another area of contention that he had outlined in his initial list (Line 11: "[**But**] **three hours a week isn't exactly <u>athletic</u>**"). Here, emphasizing the word "athletic" functions to mark a shift in the conversation in terms of the idea being disputed. It also serves to maintain Student 3's original, extended critique from Line 4, as students then begin challenging the concept of athleticism. When the questionable validity of the data is further supported by Student 8 in Line 16 (e.g., "…<**the results of the test <u>can</u> change depending on how hard the person tries to excel** (.) **how well they follow directions** (.) **or if they're tired**.> **So:: it's <u>not</u> a very reliable** [**test**]"), in Line 17, Student 3 returns to, and expands upon, the second idea he had described in his list, again shifting the topic of contention and providing a new avenue on which student critique could continue.

The same interactional move can be seen in Excerpt 8, which took place during the second group's seminar in Ms. Allen's class (during which students debated the question about the Indian Plate). In Line 1, Student 10 describes a list of claims that she has issues with, which other students had previously contributed to the discussion ("I mean (.) but the Eurasian Plate (.) if it keeps on creating- (.5) if you say that it keeps on creating the Himalayas (1) **but then the other plates of the Eurasian Plate how will it <u>move</u> if it keeps on creating**? (1) It will just <u>stay</u> there in fifty million years (.)").The pauses and silence between certain words functioned to demarcate the different claims with which Student 10 disagreed (in particular, phenomenon at plate boundaries, and timing). Student 14 then disputes a claim Student 10 had mentioned (Line 2). In Line 4, they further articulate their dissent by saying, "**It will <u>eventually</u> move** (.) **I don't think it will be in fifty years or more**," placing emphasis on the word "eventually," which served to highlight the area of disagreement. In Line 7, Student 10 then shifts the conversation to one of the other points with which she had originally disagreed ("[**But what if-] what if the Eurasian Plate decided to move**?"), which served to maintain her original critique from Line 1.

Excerpt 8

1	Student 10:	I mean (.) but the Eurasian Plate (.) if it keeps on creating- (.5) if you say that it keeps on creating the Himalayas (1) **but then the other plates of the Eurasian Plate how will it <u>move</u> if it keeps on creating**? (1) It will just <u>stay</u> there in fifty million years (.) [and I believe-]
2	Student 14:	[**But like**] **the Indian Plate will eventually have to run out of land to keep on creating onto the** [**Himalayas**]

3	Student 10:	[Yeah] exactly so it if-
4	Student 14:	**It will <u>eventually</u> move** (.) **I don't think it will be in fifty years or more**
5	Student 10:	But- but it's like (.) for- it means like fif- (.5) so you're saying that in fifty million years the Himalayas will still <u>be</u> there?
6	Student 14:	[Sure]
7	Student 10:	[**But what if-] what if the Eurasian Plate decided to move**? Like (.) there's a lot of [chance-]
8	Student 14:	[I think it] (.) I think it would take the Himalayas with it because it's already on the Eurasian Plate.

Furthermore, this move functioned to offer peers a new path of ideas to debate. Across these examples, critique was prompted, and sustained, by instances of students listing points of disagreement.

Discussion

The social network analysis of the science seminar transcripts enabled us to develop better understandings of the interactional moves around critique during the focal groups' science seminars. Furthermore, the discourse analysis highlighted the interactional moves that prompted students to critique their peers' arguments. Findings stress the relationship between discourse patterns and interactional norms (particularly in terms of what they might look like when students engage in dialogic interactions during argumentation discussions), and also suggest the need to expand our perspectives of *who* can prompt for critique during an argumentation activity.

Discourse Patterns and Interactional Norms

Students infrequently have opportunities to engage in critique in the science classroom (Henderson et al., 2015). This may be in part due to the dominant perspective that science education involves students learning an established body of knowledge (Osborne, 2014). Within this perspective, there is no room for students to contest developing understandings of scientific phenomenon with peers, as an established set of facts and ideas does not enable students to grapple with "uncertainty" (Manz, 2014). Moreover, the dominant perspective of what it means to learn science informs schooling practices, especially those that relate to students' interactions amongst themselves and with the teacher. For instance, pervasive discourse patterns in science classrooms (e.g., initiate-response-evaluate, IRE; Cazden, 1988; Lemke, 1990) transmit the message that what is valued is what students know, and not how they come to know it (Herrenkohl, Palincsar, DeWater & Kawasaki, 1999). Thus, prevalent interactional patterns in science classrooms minimize opportunities for students to critique (Henderson et al., 2015). However, realizing the new demands proposed by educational reform efforts will necessitate shifts in how learning it is carried out in the science classroom. These shifts will require students and teachers to interact with each other in ways with which they might be unfamiliar.

As demonstrated by the sociograms, students are capable of engaging in critique. Moreover, partaking in this dialogic component of argumentation included classroom members carrying out interactional patterns that differ from those that traditionally dominate science classrooms. Across the focal groups' seminars only students were seen critically evaluating or disagreeing with their classmates; neither of the teachers were captured in these sociograms as critiquing students' ideas. This is different from IRE-style discourse in which the teacher is central to the interactional pattern (Scott et al., 2006). Thus, conditions that foster dialogic

interactions amongst students during argumentation activities necessitate a shift in the role of the teacher (Schwarz, Neuman, Gil, & Ilya, 2003; Martin & Hand, 2009). For example, both teachers in this study were critical in creating spaces during the discussions that stimulated and allowed for student critique. Ms. Ransom rarely spoke during her students' seminars, and did not actively prompt for student critique by making any of the interactional moves that Ms. Allen did. Yet, her silence during times that students were critiquing sent the implicit message that critique was permissible and an expected action during an argumentation discussion. Consequently, her students' seminar did not include interactional patterns of students talking to and through the teacher, but instead included instances of them directly critiquing their peers' arguments.

Thus, the interactional patterns around critique conveyed an important message about the types of interactions that are valued in argumentation. As seen through the sociograms presented earlier, some students were seen speaking directly to peers and disagreeing with points brought up during the science seminar. Because the teachers did not reprimand or correct students during these instances, the message communicated to the class was that this type of behavior is expected during argumentation discussions. Furthermore, because the teachers in the focal classrooms were not observed evaluating students' ideas (a common teacher practice during IRE discussions; Mehan, 1979), students might have understood that it was on them, and not the teacher, to carry out critique. Yet, it must be noted that across the focal groups' seminars, there were students who did not partake in critique (i.e., the benched actors to the left of each sociogram), which might be indicative of students' hesitancy and discomfort taking on such a role during classroom discussions since it is not one with which they are accustomed.

Prompting for Critique

Research in argumentation has shown that the teacher plays an important role in terms of encouraging students to partake in certain aspects of this science practice (e.g., Simon, Erduran & Osborne, 2006; McNeill, 2009). For example, McNeill and Pimentel (2010) found that a high school teacher's use of open-ended questions during whole class discussions prompted her students to engage in the structural and dialogic components of argumentation. Specifically, this teacher's questions resulted in students supporting their claims with evidence and reasoning, and also of interacting with their peers. Similarly, in this study, Ms. Allen and Ms. Ransom's roles during the science seminars, although different, stimulated dialogic interactions amongst students, specifically in terms of critique. In Ms. Allen's case, the teacher actively carried out interactional moves that engendered student critique (e.g., clarified or repeated a student's argument). This suggests that students might benefit from in-time supports that help them see how their ideas relate to those of other students. In contrast, Ms. Ransom was not observed prompting critique; in fact, she rarely spoke during her students' seminars. However, the absence of Ms. Ransom's input – particularly during times that her students were evaluating and disagreeing with their peers' ideas – conveyed to her students that critique was an acceptable, and expected, action during argumentation discussions. This finding highlights the ways that teachers can encourage dialogic interactions amongst students by physically removing themselves from the conversation. As such, teachers might find that stepping back and preoccupying themselves with something (like taking notes of ideas brought up) helps their students take charge during argumentation activities. Furthermore, Henderson and colleagues (2015) posited that students need teacher scaffolding in order to successfully learn and engage in critique. However, these findings suggest that students, not just the teacher, can support their peers in carrying out this discursive move.

As exemplified in our findings, during the science seminar activity students too made particular interactional moves that prompted others to engage in critique. For instance, Student 3 in Ms. Ransom's class often articulated a challenging statement, which invited responses from his peers as he positioned certain ideas as unreasonable and consequently disputable. The findings suggest that, while we can obtain insight from teachers' instructional strategies, there is also much we can learn from observing students. Beginning to develop an understanding of what supports student critique is the first step in a process towards normalizing this type of interaction in science classrooms. Some of this knowledge can be integrated into classroom instruction to further support students who may feel uneasy with this practice. For instance, explicitly teaching interactional moves that trigger student interactions and critique might help students slowly feel more comfortable taking on those types of behaviors (which are traditionally carried out by the teacher) during class discussions. This certainly was the case with the student discussion leader in Ms. Allen's class, as she began copying the teacher and asking students if they agreed or disagreed with a peer's idea. These strategies could help make engaging in critique an integral part of science education, which will have numerous benefits for students, including deepening their learning and increasing motivation (Ford, 2015; Henderson et al., 2015).

Acknowledgements

This work was supported in part by the Constructing and Critiquing Arguments in Middle School Science Classrooms: Supporting Teachers with Multimedia Educative Curriculum Materials project, funded by National Science Foundation grant DRL-1119584. Any opinions expressed in this work are those of the authors and do not necessarily represent either those of the funding agency or Boston College. We would like to thank Rebecca Louick and Erin Bleck for their assistance with data analysis, as well as Lisa Marco-Bujosa for her feedback on this work.

References

Andriessen, J. (2007). Arguing to learn. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 443–460). Cambridge, England: Cambridge University Press.

Atkinson, J. M. & Heritage, J. (1984). *Structures of social action*. Cambridge: Cambridge University Press.

Berland, L. K. (2011). Explaining variations in how classroom communities adapt the practice of scientific argumentation. *Journal of the Learning Sciences*, *20*, 625-664.

Berland, L. K., McNeill, K. L., Pelletier, P. & Krajcik, J. (2017). Engaging in argument from evidence. In. C. V. Schwarz, C. Passmore, & B. J. Reiser (Eds.). *Helping students make sense of the world using next generation science and engineering practices* (229-257). Arlington, VA: National Science Teachers Association.

Berland, L. K. & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education, 93,* 26-55.

Berland, L. K. & Reiser, B. J. (2011). Classroom communities' adaptations of the practice of scientific argumentation. *Science Education, 95,* 191-216.

Borgatti, S. P., Everett, M. G. & Freeman, L. (2006). UCINET 6 for Windows (Version 6.286). Lexington, KY: Analytic Technologies.

Cazden, C. B. (1988). *Classroom discourse: The language of teaching and learning.* Portsmouth, NH: Heinemann.

Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the classroom: How the classroom environment shapes students' relationships with each other and with concepts. *Cognition and instruction*, *22*(4), 467-498.

Creswell, J. W. (1999). Mixed-method research: Introduction and application. In G. Cizek (Ed.), *Handbook of educational policy*. San Diego, CA: Academic Press.

Creswell, J. W., Piano Clark, V. L., Gutmann, M., & Hanson, W. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209-240). Thousand Oaks, CA: Sage.

Ford, M. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition and Instruction*, *30*(3), 207-245.

Ford, M. (2015). Educational implications of choosing "practice" to describe science in the Next Generation Science Standards. *Science Education*, *99*(6), 1041-1048.

Gee, J. P. (2005). *An introduction to discourse analysis: Theory and method* (2nd ed.). New York, NY: Routledge.

Goffman, E. (1959). *The presentation of self in everyday life.* New York, NY: Doubleday.

Goffman, E. (1981). *Forms of talk*. Philadelphia, PA: University of Pennsylvania Press.

González-Howard, M. & McNeill, K. L. (2016, April). *Using social network analysis to examine interactional patterns in scientific argumentation.* Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

Gumperz, J. J. (1992). Contextualization and understanding. In A. Duranti & C. Goodwin (Eds.), *Rethinking context: Language as an interactive phenomenon* (pp. 229-252). Cambridge, England: Cambridge University Press.

Henderson, J. B., MacPherson, A., Osborne, J. & Wild, A. (2015). Beyond construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education*, *37*(10), 1668-1697.

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the*

Learning Sciences, 8(3&4), 451 – 493.

Jiménez-Aleixandre, M. P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.). *Argumentation in science education: Perspectives from classroom-based research* (pp. 3-28). Dordrecht, The Netherlands: Springer.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R. & Mun K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*, 157-175.

Lemke, J. L. (1990). *Talking science: Language, learning and values.* Norwood, NJ: Ablex.

Manz, E. (2014). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*, 0034654314558490.

Martin, A. M., & Hand, B. (2009). Factors affecting the implementation of argument in the elementary science classroom. A longitudinal case study. *Research in Science Education*, *39*(1), 17-38.

McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education*, *93*(2), 233-268.

McNeill, K. L., González-Howard, M., Katsh-Singer, R. & Loper, S. (in press). Moving beyond pseudoargumentation: Teachers' enactments of a science curriculum focused on argumentation. *Science Education.*

McNeill, K. L., González-Howard, M., Katsh-Singer, R. & Loper, S. (2016). Lessons learned developing a teacher PCK assessment for scientific argumentation: Using classroom contexts to assess rich argumentation rather than pseudoargumentation. *Journal of Research in Science Teaching, 53*(2), 261-290.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R.W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153-191.

McNeill, K. L., Marco-Bujosa, L., González-Howard, M. & & Loper, S. (2016, April). *Curriculum Implementation for Scientific Argumentation: Fidelity to Procedure Versus Fidelity to Goals***.** Paper presented at the annual meeting of the National Association for Research in Science Teaching, Baltimore, MD.

McNeill, K. L. & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203-229.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom.* Cambridge, MA: Harvard University Press.

Miles, M., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd edition). Thousand Oaks, CA: Sage.

Mortimer, E. F. & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead, England: Open University Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press.

O'Conner, M.C, & Michaels, S. (1993). Aligning academic task and participation status through revoicing: Analysis of a classroom discourse strategy: *Anthropology and Education Quarterly*, *24*, 318-335.

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, *25*(2), 177-196.

Potter, J. & Wetherell, M. (1987). *Discourse and social psychology: Beyond attitude and behaviors.* London: Sage.

Regents of the University of California. (2012). *Plate Tectonics*. Field trial version of middle school science unit developed by the Learning Design Group. Lawrence Hall of Science.

Regents of the University of California. (2013). *Metabolism*. Field trial version of middle school science unit developed by the Learning Design Group. Lawrence Hall of Science.

Sampson, V. & Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education, 92*, 447-472.

Schwarz, B. B., Neuman, Y., Gil, J., & Ilya, M. (2003). Construction of collective and individual knowledge in argumentative activity. *The Journal of the Learning Sciences*, *12*(2), 219-256.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*, 605-631.

Simon, S., Erduran, S. & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2-3), 235-260.

Wells, G., & Mejia Arauz, R. (2006). Dialogue in the classroom. *Journal of the Learning Sciences*, *15*(3), 379-428.

Windschitl, M., Thompson, J., & Braaten, M. (2011). Fostering ambitious pedagogy in novice teachers: The new role of tool-supported analyses of student work. *Teachers College Record, 113*, 1311–1360.