

Using social network analysis to examine interactional patterns in scientific argumentation

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Reference as:

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 Education Research Association, Washington, D.C.

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In the same ways that scientists develop and revise understandings of natural phenomenon, recent efforts in education contend that students should also have an active role in making sense of nature (Duschl, Schweingruber & Shouse, 2007). Students' roles have tended to be more passive, with them primarily being listeners and receivers of information. Lemke's (1990) seminal work highlighted how the view of students as recipients of predetermined, uncontested knowledge aligns with the discursive interactional pattern that prevails in science classrooms. Specifically, this interactional pattern involves a three-part exchange in which the teacher initiates conversation by asking the class a question, a student is called upon to respond to the question, and then the teacher evaluates the students' answer (Cazden, 1988). However, reform documents (NRC, 2012) and standards (NGSS Lead States, 2013) encourage a shift in science instruction by articulating that students ought to develop their own understandings of natural phenomena through engagement in science practices, including scientific argumentation. However, the types of student-driven exchanges required by argumentation differ greatly from the interactions that occur in traditional classrooms, where students primarily speak to and through the teacher. Thus, engaging in science practices, such as argumentation, will require that students enact some of the roles typically reserved for the teacher (Crawford, 2000), and that the patterns of interaction during classroom discussions change.

Because this new view of science education calls for a significant instructional shift, in order for reform efforts to be realized, teachers and students will need to develop a strong understanding of what it means to learn and do science through engagement in science practices (Duschl, 2008). To transform discussions in science classrooms towards encompassing argumentation, we need a stronger understanding of what argumentation discourse patterns look like, paying particular attention to teacher and student roles (Kuhn & Reiser, 2006). While the structural component of argumentation has been studied in many ways (e.g. McNeill, Lizotte, Krajcik & Marx, 2006; Sampson & Clark, 2008; Sandoval & Millwood, 2005), these analyses do not capture the highly interactive aspects of this science practice, which include the actions students take while constructing arguments and persuading their peers about the strength of a particular claim (Ford, 2008). As such, research is needed to understand how to support students in critiquing one another, as well as building off of the ideas of their peers as they engage in the process of argumentation (Andriessen, 2007).

Although several methods have been used to analyze argumentation (Erduran, 2008), new methodologies are needed for characterizing when and how students engage in this science practice, especially through the language modality of talk. In particular, these analytic techniques must capture the complex, social dimensions of argumentation. We propose social network analysis (SNA) as one way to attend to this demand. SNA is a methodology that seeks to identify underlying patterns of social relations based on the way actors in a network are related to one another (Scott, 1991; Wasserman & Faust, 1997). A classroom can be construed as a social network in which the teacher and students are actors (Borgatti & Ofem, 2010). The recent body of work using SNA to examine argumentation suggests that this technique has potential for providing insight into the interactional patterns that occur while students engage in this science practice. This insight is a necessary first step towards identifying and developing instructional supports for the dialogic aspects of this science practice. Thus, in this study we explore the ways that SNA can be used to examine interactional patterns in argumentation discussions.

Theoretical Framework

Scientific Argumentation

Researchers in the field of science education have different theoretical perspectives about the role of argumentation in teaching and learning. As a result, many 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 study, we conceptualize this practice as encompassing both a structural and dialogic component (Jiménez-Aleixandre & Erduran, 2008; McNeill, González-Howard, Katsh-Singer & Loper, 2016). The structure of an argument includes justifying claims using both evidence and reasoning (McNeill et al., 2006). Specifically, a claim is a conclusion about a problem, or an answer to a question; evidence is comprised of scientific data (i.e. accurate measurements and observations) that is both appropriate and sufficient to answer the claim; while reasoning is an explanation of how the evidence supports the claim that often includes scientific principles (McNeill & Krajcik, 2012). However, unlike prior work that just examined the structural pieces of students' arguments (i.e. whether students included reasoning in their written arguments; McNeill et al., 2006), we explore argument structure *in use* – the ways that students include, ignore, and debate claims, evidence and reasoning during argumentation discussions.

In terms of the dialogic component, this highly interactive practice also encompasses students critiquing and debating the strength of a particular claim with others, as well as the revision of claims (Ford, 2008; Ford 2012). Although described as two different aspects of this practice, the structural and dialogic components of argumentation are ideally synergistic: dialogic interactions lead to improvements in the structure of arguments (e.g. more relevant pieces of evidence, clearer reasoning), and while considering different structural aspects (e.g. which of two competing claims is stronger) the dialogic process in which individuals question, critique and build on each other's ideas can be supported. The literature on argumentation has tended to focus on argument structure (i.e. whether students justify claims with evidence) or the impacts of a curricular intervention on increasing the occurrence of this science practice in the classroom (Clark, Sampson, Weinberger & Erkens, 2007). However, students need more than a strong understanding of an argument's structure to engage in argumentation (Ford, 2012). Although some research has examined the classroom community supporting argumentation (Berland & Reiser, 2011; Berland, 2011; Duschl & Osborne, 2002), few studies have attempted to synthesize the interactions that take place during argumentation. Potentially, this is because of the complex nature of the exchanges students engage in while partaking in this science practice.

Methodological Approaches to Analyzing Argumentation

The methods that researchers have utilized to evaluate argumentation discussions in classroom instruction vary depending on their theoretical frameworks of this science practice, as well as the focus of their work (Erduran, 2008). A few studies have attempted to clearly visualize the complex ways that students engage in argumentation. For example, interested in studying student participation during argument discussions, Maloney & Simon (2006) constructed "Discussion Maps" of students' arguments. Their mapping technique provided a visual way of evaluating how students reviewed evidence and iteratively discussed arguments, ignoring certain pieces of evidence that were presented by peers and pursuing others. Additionally, this approach enabled them to see which students were involved in the discussion. However, in a practical sense this diagrammatic technique had limitations in that even a short argument transcript results in numerous pages of Discussion Maps, which are not easily discernible.

A more novel approach for studying student participation in argumentation discussions has been through social network analysis (SNA). This analytic technique can help make visible patterns of social relations between individuals in a common network, such as students in a classroom (Carolan, 2014). For instance, Yoon (2011) explored the visualization affordances of SNA, using sociograms – images of particular types of relations in a network – that illustrated patterns of students’ interactions as an intervention for improving group-level processes and learning outcomes. Handheld electronic devices were used to archive participants’ interactions, which then created sociograms of the communication network. Students were then shown the sociograms and provided with three questions to scaffold their observations: 1) What do you think your position in the graph means? 2) To whom have you spoken most consistently over time and why? 3) Are there any patterns or trends that you see between the two graphs? What is happening at the group level? This intervention was done in order to understand whether viewing the sociograms had any influence on students’ behavior in future argumentation discussions. Results from the intervention indicated that the students’ rules about who to talk to during the argumentation activities shifted from non-reflective (i.e. random selection, peers who had similar ratings as their own, friends or familiar people) to reflective (i.e. peers who had different ratings than their own, information seeking), and subsequently their understanding of the socioscientific phenomena being explored became deeper and more complex.

Most recently, Ryu and Lombardi (2015) argued that applying multiple analytic techniques allows for a richer understanding of what interactional patterns occur while students engage in argumentation with peers, as well as insight into why and how engagement might be occurring. Exemplifying the utility of mixed methods, they presented findings from a classroom that encompassed both 3rd and 4th graders, in which an experienced science teacher intentionally attempted to encourage less engaged students to participate during argumentation discussions by assigning and rotating different roles and responsibilities. Employing SNA and critical discourse analysis allowed researchers to illustrate how and why over time students’ collective engagement increased. For instance, one student who was often in the periphery of group discussions became a more central player later in the school year as he gained comfort in working with his peers. However, similar to the Yoon (2011) study previously discussed, this work explored student participation more generally (i.e. the extent to which students talk with peers), and did not tease apart the substance of students’ exchanges in terms of argument structure and dialogic interactions. Our study intends to demonstrate how sociograms can be used to illustrate the nuances of an argumentation discussion across both the structural and dialogic components of this science practice (e.g. who asks questions, and to whom; who builds on their peers’ ideas; who references evidence in their contributions, etc.).

Methodology

Curricular Context

The data collection for this study took place during the 2013-2014 school year, in the context of teachers piloting a life science unit called *Metabolism* (Regents of the University of California, 2013) that included a specific emphasis on argumentation. The *Metabolism* unit focused on how, at the cellular level, the human body systems work together in order to produce energy by getting matter to and from cells. Teachers’ instructional materials were delivered digitally (e.g. an iPad or website), and students received notebooks that contained all of the handouts they would need for the unit. Furthermore, virtual simulations about the human body

systems were incorporated into many of the lessons for students to manipulate, which were delivered digitally on a tablet computer.

The *Metabolism* unit concluded with a science seminar: a whole class activity in which students orally debated explanations to a question using evidence analyzed in previous lessons. During the science seminar, students were split into two groups, and the classroom was set up into two concentric semi-circles. Students sitting in the inner semi-circle debated the question, while those in the outer semi-circle listened actively and completed an observation sheet. Halfway through the class time, the two groups switched. During the entirety of the seminar, students were responsible for driving the conversation, listening, critiquing and responding to one another as they debated the guiding question. The teacher was expected to physically step back and watch from the side, listen silently, and interject only when necessary. In terms of argumentation, this activity encompassed both the dialogic and structural components of this science practice: students engaged in dialogic interactions (e.g. questioned one another) while they constructed and refined the structure of an argument (e.g. explained how a particular piece of evidence supported a claim).

Specifically, in the *Metabolism* science seminar students debated the question: When a person trains to become an athlete, how does her body change to become better at releasing energy? Throughout the unit students had explored how athletic training improves body functions, learning that through the process of cellular respiration energy is released into cells, which supports movement, growth and repair. Prior to the science seminar, students had been divided into three groups, each of which were given data from studies about bodies' responses to exercise. Analyzing these data enabled students to construct many claims in response to the guiding question. Subsequently, the multiple claims gave students a need for interacting with one another in order to determine which claim best explained the phenomenon of interest.

Participants

The participating teacher, Ms. Ransom (a pseudonym) and students for this study were selected from part of a larger project (McNeill, Marco-Bujosa, González-Howard & Loper, 2016), in which the unit previously described was being piloted. Ms. Ransom, who had over 20 years of teaching experience, was one of four 7th grade science teachers at her public middle school (i.e. grades 6-8). This school, which catered to students from ages 11-14, was located in a suburban city in the northeastern United States. In terms of argumentation, Ms. Ransom had attended one workshop about this science practice before the start of the pilot, and self-reported having incorporated argumentation into her classroom instruction a few times.

Data Source

Ms. Ransom's class was split into two groups during the focal lesson, each of which had an opportunity to engage in the science seminar activity. As such, this study examined a video recording of two science seminars. These science seminars ranged in length, with Group 1's lasting approximately twelve minutes, and Group 2's nearly ten minutes. The two discussions were transcribed. Transcriptions also included information about whether an individual pointed to or referenced something during their turn, with the action italicized in brackets within the transcript (e.g. [*pointing to data table in notebook*]). It was necessary to include actions in the transcripts because individuals' non-verbal contributions (e.g. a student points to a data table when disagreeing with a peer's argument, or the teacher taps on a student's shoulder to encourage them to participate) are also important aspects for understanding how the argumentation discussion unfolded.

Data Analysis

Overview of the analytic technique. In analyzing this data we were ultimately interested in visualizing and exploring the interactions that occurred during both science seminars, which is why we decided to use SNA. Several concepts are fundamental to a discussion of SNA, including actors, ties, nodes, and structure. The social units examined through SNA are typically referred to as actors. Actors can represent either discrete individuals (e.g. a teacher) or collective social units (e.g. the 8th grade teachers of a particular elementary school). Ties capture the ways that actors are connected to one another. Depending on the theoretical and empirical interest of a study, different types of ties can be examined through SNA, such as similarities, social relations, mental relations, interactions and flows (Borgatti & Ofem, 2010). Furthermore, the unit of analysis in SNA is not a particular actor, but instead the interactions that occur between two or more actors in a given network (de Laat, Lally, Lipponen & Simons, 2007). As such, SNA offers a means by which to map interactions between actors in a network, visualizing and quantifying certain characteristics of these interactions. In this study, the interactions that we examined were those that occurred as the students in Ms. Ransom's classroom engaged in argumentation. Specifically, we operationalized and examined "argumentation ties" between classroom members as they participated in the science seminar.

Furthermore, central to SNA is the idea that the structure of the network, and one's position in it, are related to opportunities and outcomes (Carolan, 2014). The sociograms we created of the various aspects of the science seminars showed whether particular types of interactions were occurring between all actors or whether some actors were engaging more, or less, with other group members (Haythornthwaite, 2002). The sociograms also highlighted individuals who were positioned in interesting ways in the network, including people who were at the periphery of the network, central actors, and even individuals who served as bridges between some participants and the rest of the group. There were many steps that we had to take after transcribing the seminars before conducting the SNA, including: breaking the transcriptions into utterances; coding the utterances across argument structure, dialogic interactions, and ties; and creating binary, directed matrices. We will now briefly describe each of these steps.

Breaking the transcripts into utterances. Similar to the work of other researchers who have examined classrooms engaged in oral argumentation (e.g. McNeill & Pimentel, 2010), in preparation for analysis, the transcription of each science seminar was broken up into utterances. An "utterance" was operationalized as an idea or contribution to the discussion that ideally captures an argumentation component (i.e. a structural feature of an argument, a dialogic interaction, or a combination of both). However, sometimes utterances are unrelated to argumentation components (e.g. a student asks a question irrelevant to the topic being debated, such as, "Can I go to the bathroom?"). Depending on the number of ideas included in a turn of talk, an individual's turn could include one or multiple utterances. The transcript in Table 5 provides examples of utterances, which are denoted by back-slashes (e.g. /utterance/). Two raters independently broke 20% of each science seminar transcript into utterances and obtained 98.5% inter-rater reliability.

Coding the utterances. We next coded each utterance from the science seminar transcripts using two different coding schemes – one that focused on argument structure, and the other on the dialogic interactions that occurred during the argumentation activity. Doing so enabled us to operationalize the different types of argumentation ties that we later examined. These coding schemes were developed from both the theoretical framework around scientific argumentation, and an iterative analysis of the science seminar transcripts (Miles & Huberman,

1994). Table 1 and 2 include a synthesized version of both coding schemes. The examples for each code are embedded within the context of the *Metabolism* unit's science seminar.

Table 1: Coding Scheme for Argument Structure

Code	Description	Example
Claim	An answer to the science seminar's guiding question	"I think that when a person trains to become an athlete their cells change by having more mitochondria."
Evidence	Scientific data (i.e. measurements or observations that are either firsthand or secondhand) that either support or refute a claim	"Test one showed that the mitochondrial proteins was greater in the athletic twins."
Reasoning	An explanation of how the evidence supports the claim, which often includes science ideas	"Having more mitochondrial proteins means having more mitochondria in cells. Higher amounts of mitochondria can manage more oxygen and glucose to release more energy"
Other	All other utterances not included in the three previous codes for argument structure	"I don't know."

The coding scheme for argument structure was informed by the work of researchers who have studied and evaluated argumentation writing (McNeill et al., 2006) and talk (McNeill & Pimentel, 2010). In terms of an argument's structure, we were only interested in claims, evidence and reasoning related to the science seminar's guiding question. We did not code for other arguments or conversations that took place during the debate. Utterances that were not captured by the code for claim, evidence or reasoning received a code of "Other." The utterances that were coded as "Other" ranged, from a student asking about the directions of the activity (e.g. "Do we have to raise our hands before we talk?"); to someone voicing an off topic comment (e.g. "I was on the green team when I played basketball") to students discussing ideas that were tangentially related to the science seminar's guiding question (e.g. the number of miles a person needs to walk daily to be considered athletic). The latter example is what occurred most often when this code was assigned. As such, each utterance was classified under one of four possible argument structure codes.

Table 2: Coding Scheme for Dialogic Argumentation

Code	Description	Example
Questioning	Asking about some aspect of the discussion	"Does training to become an athlete cause you to have more mitochondria or bigger mitochondria?"
Critiquing	Evaluating some aspect of the discussion, which may include feedback	"I think the experiment where your data comes from is flawed. Just because they're twins doesn't mean their bodies are the same."
Building on other's ideas	Recognizing some aspect of a previous contribution and utilizing it to further the	"Both of those are good points, and I actually think it's those two factors combined. So an athlete's body is better at releasing energy because of a

	discussion	combination of a larger lung capacity, and more mitochondria.”
Other	All other utterances not included in the three previous codes for dialogic interactions	“When I played soccer, I practiced twice a week for three hours each training.”

In addition to the structural elements of an argument that students used during the science seminar, we were also interested in the dialogic interactions between the classroom members as they engaged in the debate (see Table 2). The coding scheme for the dialogic interactions was informed by the work of Ford (2008; 2012) and Jiménez-Aleixandre & Erduran (2008). In terms of dialogic argumentation, we were only interested in interactions related to the science seminar’s guiding question. Thus, utterances that were not captured by the code for questioning, critiquing or building on other’s ideas received a code of “Other.” Utterances that were coded as “Other” tended to occur when students simply read their arguments from their notebooks, without making any connections to the peers’ prior contributions. As such, each utterance was classified under one of four possible dialogic argumentation codes. Two raters independently coded 20% of each science seminar transcript across both coding schemes, obtaining a 94.9% inter-rater reliability. Any coding disagreements that arose were resolved through discussion.

Once the transcripts were coded across both argument structure and dialogic interactions, we determined the connection (or ties) between turns of talk during the science seminar (i.e. who was talking to whom). These ties were important to track in order to conduct the SNA. Although all participants may hear any contribution in a group discussion, a turn is typically made as a response to a specific participant in the group. As such, the following sources were used to identify the recipient of a turn: 1) following who talks after whom, 2) reading the content of a response, and 3) through gestures seen in the video recordings. There were exceptions to these rules, such as when the teacher interrupted the debate because students were getting off task, to remind the entire class of the guiding question. Furthermore, it was not uncommon for a speaker to respond to multiple participants within a single turn. In these cases, the turn was separately marked for each particular participant to whom the speaker responded (see examples in Table 5). Again, two raters independently coded 20% of each science seminar transcript in terms of ties and achieved 95.5% inter-rater reliability. The few disagreements that came up when coding for ties were resolved through discussion.

Creating matrices. Afterwards, we created binary and directed matrices (Carolan, 2014) of argumentation ties for both the structural and dialogic contributions from each science seminar. The term “binary” refers to whether a tie between two actors does or does not exist (i.e. 0 = does not exist, 1 = exists), while the term “directed” refers to whether or not a comment is reciprocated. The dimensions of each matrix were comprised of the students in a seminar group and Ms. Ransom, with each actor represented by both a row and column. These matrices were then used to conduct the SNA with UCINET 6 (Borgatti, Everett & Freeman, 2006) software. This software program includes NetDraw, a visualization tool with advanced graphing features. Specifically, we used NetDraw to create sociograms that illustrated various aspects of the argumentation discussions. Sociograms are visual representations of ties between actors in a network (Katz, Lazer, Arrow & Contractor, 2004). Because sociograms shed light on the “flow” of information and/or other resources that are exchanged between actors in a network (Thorpe, McCormick, Kubiak & Carmichael, 2007), they can provide insight into the interactional patterns during the science seminars across both the structural and dialogic components of

argumentation. For instance, while one sociogram showed who was engaged in critiquing (as well as who was the subject of this critique), another revealed who was presenting evidence in support of a claim being made. We created 9 sociograms for each discussion – one for each type of argumentation tie of interest (i.e. claim, evidence, reasoning, questioning, critiquing, building), as well as one that cut across all structural codes, one that cut across all dialogic codes, and one that portrayed general participation. We created a sociogram for general contribution to illustrate what is captured and lost by evaluating student engagement with this lens alone. This analysis resulted in a total of 18 sociograms, of which we will focus on a subset in this paper.

Findings

The social network analysis revealed variation in how Ms. Ransom’s students engaged in the science seminar activity. We begin with an overview of the two groups’ science seminars, highlighting the ways that the students’ debates compared in terms of teacher and student contributions, as well as across the structural and dialogic components of argumentation. This is followed by a more in depth discussion of a subset of sociograms. Specifically, we describe how the two groups’ sociograms related for general participation, dialogic interactions, and critiquing.

Overview of the Two Science Seminars

Before delving into the sociograms that came out of our analysis, we will first briefly discuss the similarities and differences between the science seminars in Ms. Ransom’s class. Table 3 and Table 4 offer a glimpse into the two groups’ debates. Interestingly, although Group 2’s seminar was 2 minutes shorter than Group 1’s, there were more turns of talk, and subsequently more utterances, in Group 2’s discussion. Despite this difference, both group’s science seminars were primarily driven by the students, with the teacher playing a minor role. Specifically, nearly 84% of the utterances in Group 1’s debate, and 90% of the utterances in Group 2’s discussion came from the students.

Table 3: Breakdown of Science Seminars

Turns	Total #	Group 1	Group 2
		95	130
	Total #	161	185
Utterances	Total # Student	135 (83.9%)	168 (90.8%)
	Total # Teacher	26 (16.1%)	17 (9.2%)

The argumentation breakdown across the groups’ seminars for both argument structure and dialogic interactions can be seen in Table 4. Overall, Group 1’s debate was stronger with regards to students attending to the structural aspects of an argument, particularly in terms of evidence. Group 1 tended to reference evidence both when students provided justification for their claims and when they asked peers questions about the studies other groups analyzed prior to the debate. On the other hand, Group 2’s science seminar had higher instances of students engaged in the dialogic aspect of this practice, specifically around critiquing. Students in Group 2 were frequently heard making critical remarks about their peers’ contributions, especially when evaluating the validity of the studies other students’ examined. However, attending often to the structural elements of an argument, as Group 1 did, does not subsequently require low dialogic interactions. Each utterance from the seminar was coded across both argumentation components.

For instance, an utterance such as, “How old were the twins in your study?” would have received a code of Evidence for structure, and Questioning for dialogic interactions.

The information in Table 3 and 4 is helpful for identifying commonalities and differences amongst Ms. Ransom’s students’ debates. However, these tables do not provide insight into *who* exactly was involved in the various aspects of the argumentation discussion, and to what degree they were engaged in the seminar. The benefit of using SNA to analyze the science seminars is that it allows for a visualization of what is happening with respect to the interactions amongst different classroom members during the argumentation discussion, which is not otherwise easily discernable. In this paper, we will illustrate the affordances of employing SNA to examine interactions during argumentation discussions, focusing on the code of “Critiquing.” Although many interesting aspects arose from the sociograms, we have chosen to highlight this type of interaction for two reasons: 1) there was a stark difference between the two groups’ debates in terms of critiquing, and 2) critique has largely been absent from science education (Henderson, MacPherson, Osborne & Wild, 2015).

Table 4: Total Number of Utterances Across Argumentation Codes

		Group 1	Group 2
Argument Structure Codes	Claim	8 (5%)	8 (4.3%)
	Evidence	53 (32.9%)	23 (12.4%)
	Reasoning	25 (15.5%)	15 (8.1%)
	Other	75 (46.6%)	139 (75.2%)
Dialogic Argument Codes	Questioning	18 (11.2%)	13 (7%)
	Critiquing	12 (7.5%)	71 (38.4%)
	Building	44 (27.3%)	19 (10.3%)
	Other	87 (54%)	82 (44.3%)

Sociograms of General Participation

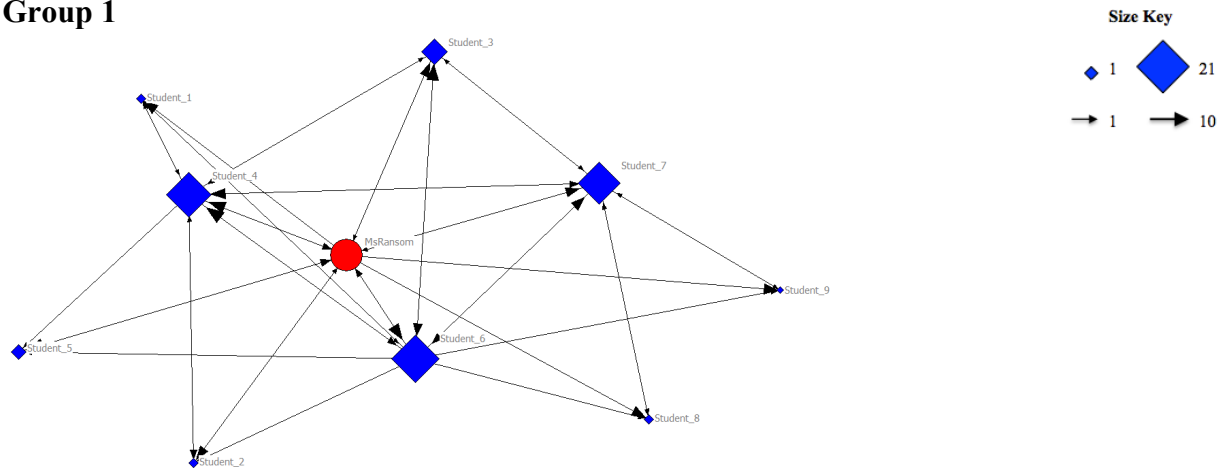
One of the outcomes of running SNA is the creation of sociograms, which consist of a set of nodes along with a set of ties that connect the nodes. In our sociograms, the nodes are either Ms. Ransom (i.e. the red circle) or the students (i.e. blue diamonds), while the ties, which may or may not be directional, capture the type of argumentation interaction being focused on (e.g. critiquing). We will begin by discussing the sociograms that were created of the general participation amongst classroom members during both science seminars (see Figure 1). In each sociogram, the size of nodes vary depending on the number of times an actor was coded as engaging in a particular type of tie, which for Figure 1 is generally speaking during the debate. In Group 1, the least number of times that an individual spoke was once, while the most was 21. On the other hand, for Group 2 there were classroom members that never spoke, though one particular student spoke 39 times during the science seminar. For Group 1’s science seminar, there are a few people who clearly stand out as having talked more, including Students 3, 4, 6, 7, and Ms. Ransom. Group 2’s sociogram indicates that Student 3 and Student 5 spoke frequently during the discussion. Furthermore, the sociograms in Figure 1 also highlight that Ms. Ransom spoke more often in Group 1’s debate than she did during Group 2’s seminar.

The ties in both networks, which are represented by the arrows between actors, are also important to examine. Figure 1 illustrates that there are more ties between nodes in the second

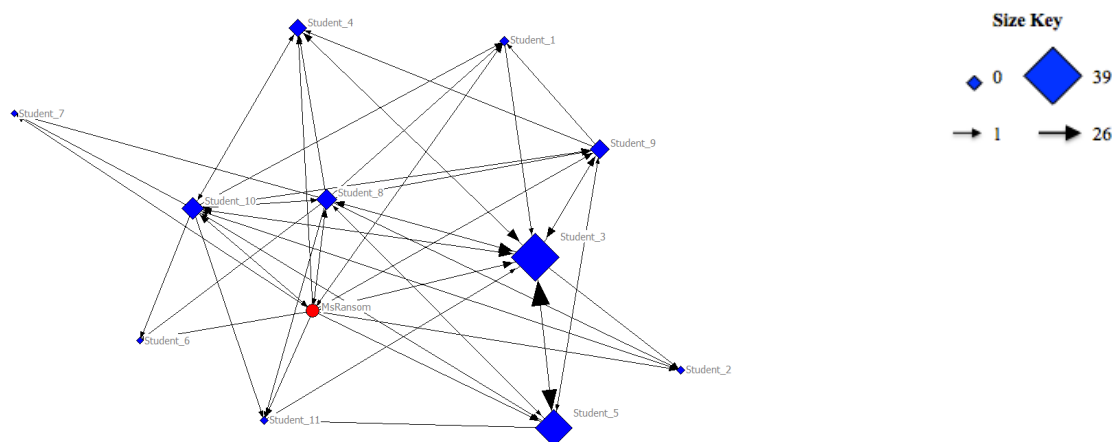
group's science seminar, which means that there were more general interactions between all classroom members during this discussion compared to the first group. Moreover, while some arrows are double headed, meaning ties were made in both directions (see Student 3 and Student 6 in Group 1), others only go from one actor to another (see Student 10 and Student 6 in Group 2). Similar to the size of nodes, the size of the arrow heads are indicative of the number of times a particular tie was made between actors (see key in Figure 1). Thus, while some individuals only spoke once to another participant during the debate, others interacted more frequently. Student 3 and Student 5 from Group 2 stand out as having engaged in a lot of back and forth during their science seminar. While the sociograms of general participation do begin to shed light on who talked during the debate, the extent to which they talked, and to whom, these visualizations do not provide information about the argumentation that took place.

Figure 1: Sociograms of General Participation

Group 1



Group 2



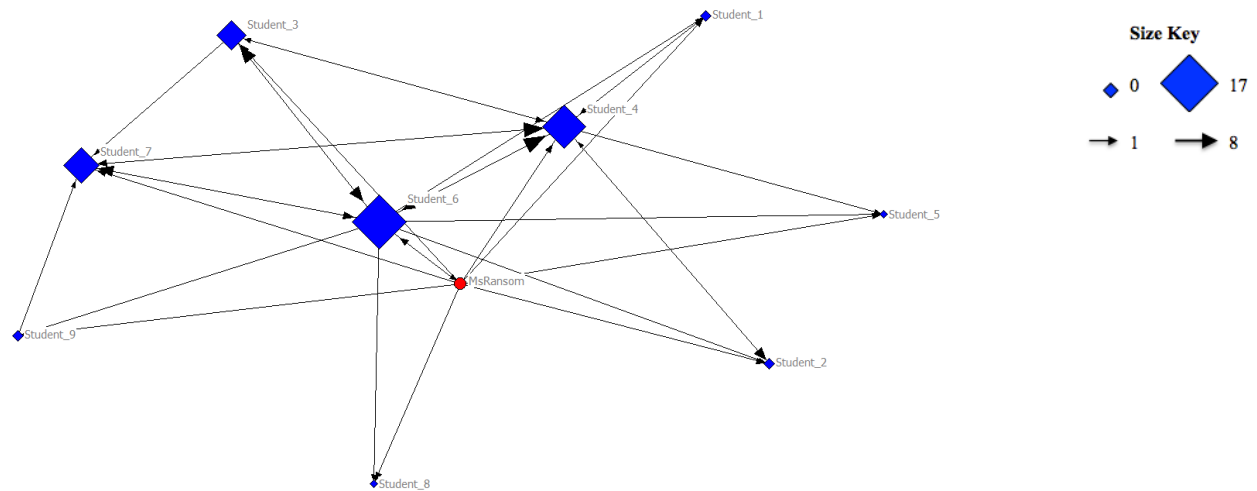
Sociograms of Dialogic Interactions

Figure 2 below illustrates the dialogic interactions that took place during both of the science seminars. All utterances that were coded “Other” for dialogic interactions, however,

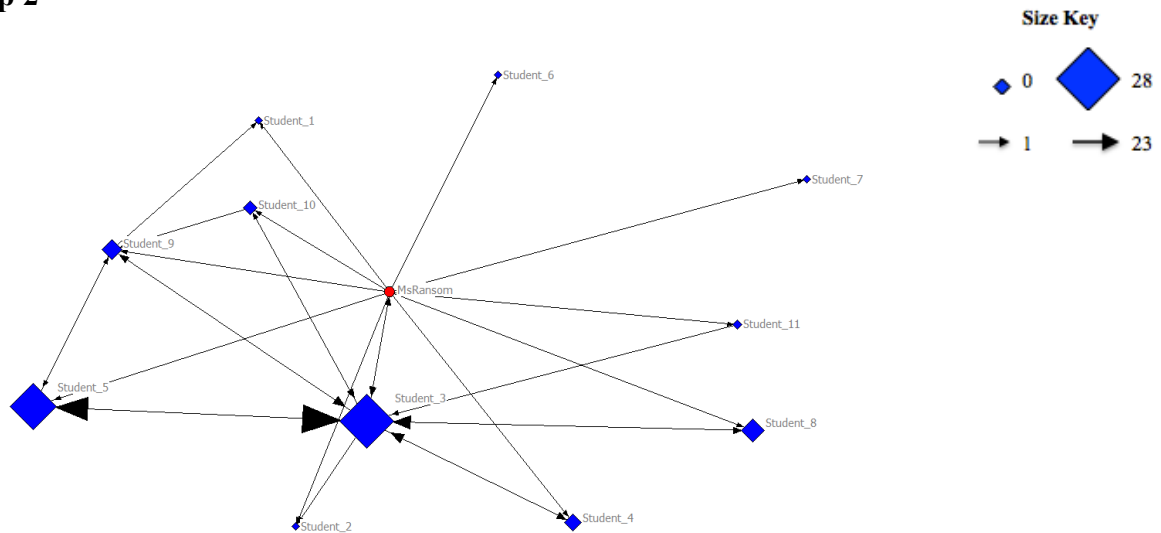
were not included in these sociograms. Thus, the sociograms in this figure cut across a subset of the codes that we analyzed for dialogic argumentation. Specifically, this subset encompassed when an individual asked a question, critiqued someone's contribution, and also when a participant built off of another person's idea (see Table 2 for details).

Figure 2: Sociograms of All Dialogic Interactions

Group 1



Group 2



With this lens, we see that these sociograms are different compared to those that showed general participation. In the cases of both groups' debates, similar students stand out as engaging in more dialogic interactions (Students 3, 4, 6 and 7 in Group 1, and Students 3 and 5 in Group 2). Meanwhile in Group 1, Ms. Ransom's node lessened in size compared to the sociogram for general participation, which means she less frequently partook in these argumentation interactions of interest. Interestingly, in both of the sociograms in Figure 2, Ms. Ransom has ties to all of the students, most of which were not reciprocated. Furthermore, between Group 1 and

Group 2 there was greater variation between the frequencies at which individuals engaged in dialogic interactions with other classroom members, with the latter group displaying more of these types of interactions (see Key in Figure 2). For Group 2 in particular, there appears to be numerous dialogic interactions targeted toward Student 3, especially from Student 5, many of which Student 3 reciprocates. While this lens offers more information about the dialogic argumentation taking place in Ms. Ransom’s class – especially in comparison with that of general participation – we do not know what specific type of interactions are occurring (i.e. questioning, critiquing or building on other’s ideas) between classroom members. Consequently, we now hone in more on these dialogic interactions, specifically highlighting individuals’ engagement in critique.

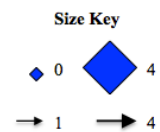
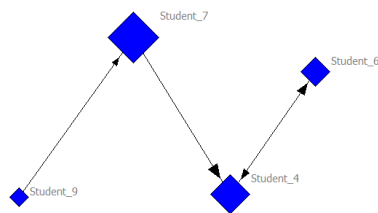
Sociograms of Critique

The sociograms in Figure 3 are quite different from the others discussed thus far. First and foremost, both of these sociograms include a fewer number of individuals because many of the students did not engage in critique.

Figure 3: Sociograms of Critiquing

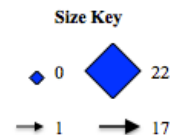
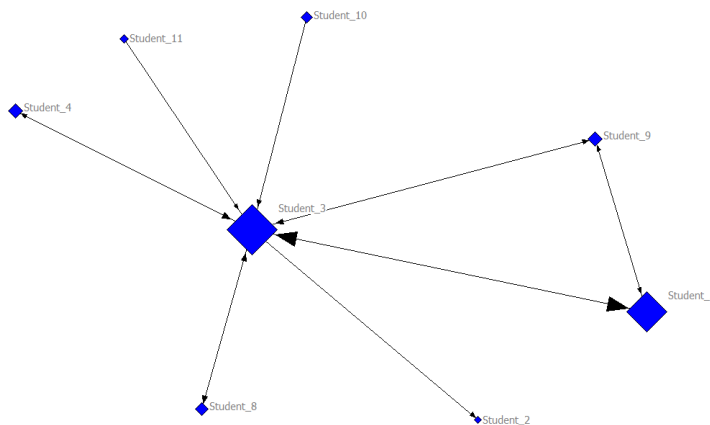
Group 1

- MsRansom
- ◆ Student_1
- ◆ Student_2
- ◆ Student_3
- ◆ Student_5
- ◆ Student_8



Group 2

- MsRansom
- ◆ Student_1
- ◆ Student_6
- ◆ Student_7



The individuals' names not engaged in critique are listed on the top left corner of each sociogram. For Group 1, six of the ten classroom members did not engage in critique, nor were they the subject of critique. Meanwhile, for Group 2, four of the twelve participants were not engaged in critique, nor were they the subject of it. Across both seminars, Ms. Ransom is included on this list, which means that she did not evaluate any of her students' contributions, and no student criticized an idea or comment made by the teacher. This indicates that the dialogic interactions Ms. Ransom was shown engaging in by the sociograms in Figure 2 must have been questioning and/or building on other's ideas. Overall, Group 2 engaged in critique more often than Group 1, which is evident both by the size of the students' nodes as well as the size of the arrowheads. In Group 1, the few students who engaged in critique tended to do so toward one other student. For instance, Student 9 critiqued Student 7; meanwhile Student 7 critiqued Student 4. The students in Group 2 also critiqued only one other classroom member, with the exception of Student 9 who critiqued two of her peers (Student 3 and Student 5). However, in the second seminar, there was one student in particular who received the brunt of critique during the argumentation discussion, Student 3. We will now briefly discuss why critique may have been more prevalent in Group 2's science seminar, and also how Student 3 was positioned to be a central actor in this network in terms of this type of argumentation tie.

Group 2 Example of Critique

As seen in Figure 3, there was one student in Group 2's science seminar who was clearly centrally located in the network in terms of critique, Student 3. The numerous arrowheads pointed at this student illustrate that he was often the subject of critique during the argumentation discussion. However, the amount of arrowheads directed from Student 3 to his peers also shows that he not only received criticism, but also gave it. The manner by which this student was situated in opposition with his peers during the debate likely impacted the structure of this sociogram. Specifically, Student 3 entered the argumentation discussion, two minutes into the debate, by openly criticizing his peers' ideas. He started by standing up from his seat in the inner circle, moving to the front of the classroom – while all of his peers remained sitting – and explained why he thought one of the studies a peer had discussed was questionable:

I think test one, study one, is a load of bogus. Okay. Thanks. The reason for that, well I have multiple reasons for that. 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 not 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 [uses his finger to make air quotes] "athletes" yet.

Before Student 3 had spoken, students had been presenting their arguments, with a few of them beginning to build off of their peers' comments. After Student 3's turn however, his peers were quick to voice their disagreement, and from then on the debate turned largely to students arguing about the validity of the studies that they were given to examine before the science seminar.

Table 5: Transcript from Group 2's Science Seminar

Turn, Timestamp & Speaker	Contribution (/utterance/)	Structure Code	Dialogic Code	Ties
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Turn #11 [5:59] Student 5	[Facing Student 3] Because it says like so what I think like this text is saying is that like the Twin A already before they conducted the test, they were already working out three hours per week. / And the Twin B was already having twelve hours umm of exercise per week. / So, I think [inaudible].	Evidence Evidence Other	Critiquing Critiquing Other	5 → 3
Turn #12 [6:20] Student 3	[Facing Student 5] I don't think that's true / because it says that, [reading from notebook on lap] "Scientists tested every person in the study in the same way at the beginning of the study," which means before they were subjected to their exercise schedules.	Other Evidence	Critiquing Critiquing	3 → 5
Turn #13 [6:30] Student 5	[Facing Student 3] Well, you exactly proved yourself wrong [laughs] / because they could have just ummm done the three hours per week of ummm athle- of training before they started even started the test.	Other Reasoning	Critiquing Critiquing	5 → 3
Turn #14 [6:41] Student 3	[Facing Student 5] But the three hours a week isn't exactly athletic.	Other	Critiquing	3 → 5
Turn #15 [6:44] Student 9	It's not athletic.	Other	Critiquing	9 → 5
Turn #16 [6:44] Student 5	[Facing Student 3] Then, it's doing a sport. / Whatever, same thing.	Other Other	Critiquing Other	5 → 3, 5 → 9
Turn #17 [6:48] Student 3	Yeah, but if they're doing a sport, they're gonna do more than three hours a week.	Other	Critiquing	3 → 5
Turn #18 [6:51] Student 4	You don't know that.	Other	Critiquing	4 → 3
Turn #19 [6:52] Student 8	Well, another way wait. Whoa, whoa, whoa, whoa, wait. Wait, you have to / [directed at Student 5] excuse you. / Because the results of the test can 'cause it says [reading from notebook on lap] 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.	Other Other Evidence Other	Other Other Building Critiquing	8 → 5, 8 → 3

Table 5 includes a portion of Group 2's discussion. As illustrated by this transcript, the conversation changed once Student 3 critiqued study one. After Student 3's turn, Student 5 voiced disagreement and the two students began engaging in a back and forth, arguing about what should count as criteria for athleticism (e.g. "But the three hours a week isn't exactly athletic."). Ms. Ransom allowed students to talk for over 5 minutes, before interjecting to remind them of the focal question they were meant to be responding. Until the interruption, other students became involved and the conversation continued focusing on evaluating the validity of the data. The teacher's reminder however, momentarily stopped the critique, causing a new student to articulate her claim. Nonetheless, Student 3's disagreement did not waver; he was adamant about his distrust for the studies throughout the entire science seminar. For instance, when Student 5 later on brought up that the results ought to be trusted because scientists had collected the data and "the scientists would make people equal." Student 3 replied, "Says who? Maybe they wanna give misleading data."

This type of evaluative back and forth was in contrast to what occurred during Group 1's science seminar. There were few instances during Group 1's debate when a student articulated not agreeing with a peer; and on those rare occasions the critique quickly fizzled out. For instance, after Student 4 claimed that athletes' bodies change by producing more mitochondria, Student 7 pushed on his idea by saying, "Aren't the cells only limited to a certain number of mitochondria? 'Cause if so, then wouldn't it be just that the mitochondria are releasing energy faster and they're more active than, you know, more than one cell?" Student 4 responded with a decisive "No." Student 7 then re-articulated her critique, to which Student 4 replied, "I don't know. No, because if there's more, more is better than less." This response ended Student 7's criticism, and the students moved on and began discussing another idea. Thus, unlike the transcript in Table 5 from Group 2's seminar when students debated an idea over multiple turns, during Group 1's discussion the critique did not last. These differences in critique were visible in the subsequent sociograms.

Discussion

Creating sociograms of the debates offered visualization into the interactions that took place during the science seminars in Ms. Ransom's class. Had we just looked at general engagement by quantifying classroom members' participation (i.e. Table 1), the two groups' science seminars may have looked relatively similar, with students contributing the majority of utterances. Coding these contributions by argument structure and dialogic interactions offered us more information about how these seminars compared and contrasted (i.e. Table 2). Specifically, doing so provided us with more insight into the ways that the seminars differed, with Group 1's debate being stronger in terms of argument structure, and Group 2's debate including more dialogic interactions, particularly in terms of critique. However, this breakdown did not enable us to distinguish *who* in the classroom engaged in *what* aspects of argumentation. Thus, the various types of sociograms that we created and discussed in this paper, each of which focused on a specific type of tie (i.e. general participation, dialogic interactions, and critiquing) shed light on particular aspects of the argumentation activity that would not have been apparent from only reading the transcription. The sociograms enabled us to see who was involved in the debate, the extent to which they engaged in the debate, and how they participated in the science seminars. For instance, the sociograms for critique emphasized the stark differences between the two classrooms' argumentation discussions. These sociograms further emphasized how Group 2's

critique centered around one actor, Student 3. This then enabled us to explore the ways that the discussion may have unfolded to result in this type of network.

Sociograms shed light on the “flow” of information that is exchanged between actors in a network (Thorpe, McCormick, Kubiak & Carmichael, 2007). In the case of this study, the sociograms that we created using SNA allowed us to examine the nature of the interactional patterns that took place as classroom members engaged in scientific argumentation. Developing an understanding of interactional patterns that are inherent to this science practice can help us to begin to identify and develop instructional strategies that facilitate shifts in discourse norms (Kuhn & Reiser, 2006). For instance, to increase particular types of dialogic interactions amongst students, it might be helpful to assign students explicit roles like “critiquer” and “synthesizer” that increase their centrality in the network. In the case of Ms. Ransom’s class, such a strategy may have helped students from Group 1 to evaluate their peers’ ideas more.

In terms of the methodology that we employed in this study, we see many potential implications that could be beneficial for both future research and classroom instruction. For instance, while we highlighted the classroom members’ status in the nodes (as either the teacher or a student, depending on the shape and color of the node), we could have also further examined other factors of interest, such as the whether participants are male or female, individuals’ races, or whether students are native English speakers, or are learning English as their second language. Including this type of information into sociograms could be of interest for researchers who want to examine the role these factors play in student engagement in argumentation. Also, like Ryu and Lombardi (2015), one could evaluate how particular students’ engagement in argumentation changes over a period of time. Additionally, similar to Yoon’s (2011) study, we could see sociograms being used as interventions, although we encourage teasing apart the nuances in argumentation discussions (e.g. who provided evidence in support of a claim, or who evaluated some aspect of a peer’s contribution). For example, if a teacher notices that her students are not questioning one another she could show them a sociogram that illustrates questioning and provide students with prompts that guide them in making sense of the visualizations (e.g. Are there any patterns that you see? Are students generally asking each other questions? Who are people generally asking questions to?). Teachers might also learn through such an intervention. For instance, while Ms. Ransom was fairly removed from the science seminar, a teacher who is experiencing challenges in letting students drive the debate – but thinks they are allowing students to do so – might find it helpful to see himself as a central actor in a network. Such a visual might help problematize their instructional approach, and perhaps prompt them to step back during the next argumentation discussion.

As reform efforts in countries across the world encourage argumentation in science education, students and teachers will need to develop an understanding of this disciplinary practice that extends beyond the structural features of an argument (Ford, 2012). Engagement in argumentation will require significant shifts in the types of interactional patterns that dominate science classrooms (Kuhn & Reiser, 2006). To support this discursive transformation, a rich knowledge base of what discourse patterns look like when classrooms engage in argumentation is needed. In this paper we describe some of the ways that SNA might be used to study interactional patterns in argumentation discussions. The visualization affordances of this analytic technique offer insight into the ways that classroom members use the structural elements of an argument as they construct, critique, and revise ideas about scientific phenomena.

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.

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