Received: 3 November 2017 | Revised: 31 January 2019 | Accepted: 3 February 2019
DOI: 10.1002/sce.21505

GENERAL SECTION

WILEY Science Education

Exploring the utility of social network analysis for visualizing interactions during argumentation discussions

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Funding information
National Science Foundation, Grant/Award Number: DRL-1119584

Abstract: Supporting student engagement in science practices requires rethinking how classroom learning occurs, specifically in terms of the interactions that help students build their own knowledge. The types of student-driven exchanges fundamental to the science practice of argumentation differ greatly from traditional classroom interactions. To help classroom talk shift toward encompassing this practice, it is important to develop understandings of discourse patterns related to argumentation. Several analytic techniques have been used to examine a classroom's engagement in argumentation. However, new methodologies are needed for capturing and characterizing the complex, social dimensions of this science practice. This study explores social network analysis (SNA) as a means by which to attend to this demand. Specifically, this study utilizes SNA on data from two middle school classrooms that participated in an argumentation discussion called a science seminar. Sociograms (images of social relations derived from the SNA) offered visualizations of interactions during the science seminars, highlighting who exactly partook in the various aspects of argumentation, how, and to what degree. Findings suggest the importance of argumentation research examining ways to better support changes in classroom interactions. This study also points to the benefits of using SNA with other types of representations to capture a classroom's argumentation.

KEYWORDS
argumentation, classroom discourse, interactional patterns, social network analysis, sociograms

1 | INTRODUCTION

In the same ways that scientists develop and revise understandings of natural phenomena through critical interactions with others, students should also have an active role in making sense of nature (Duschl, Schweingruber, & Shouse, 2007). This objective, which is expressed in recent reform efforts in education, entails a fundamental change in the goals driving science instruction: Moving away from an emphasis on students learning "a body of existing, consensually agreed and well-established *old* knowledge" (Osborne, 2014, p. 178) toward students "doing science" (Jiménez-Aleixandre, Rodríguez, & Duschl, 2000). Current reform documents (National Research Council, 2012) and standards (NGSS Lead States, 2013) encourage this shift from "learning" to "doing" science by articulating that students ought to generate their own understandings of natural phenomena through engagement in science practices, including argumentation. However, the types of student-driven exchanges that are fundamental to argumentation differ greatly from the interactions that occur in traditional classrooms, where students primarily speak to and through the teacher (McNeill & Pimentel, 2010). Thus, engaging in science practices such as argumentation requires changes to the patterns of interaction during classroom discussions, with students taking on roles that have typically been reserved for the teacher (Crawford, 2000).

This new view of science education calls for a significant instructional shift, and teachers and students will need to develop a strong understanding of what it means to engage in science practices (Duschl, 2008). In terms of argumentation, part of this understanding includes knowledge about what discourse patterns might be carried out when partaking in this science practice (Kuhn & Reiser, 2006). Discourse patterns carry messages about permissible interactions among classroom members. For instance, traditional science instruction that promotes the goal of students "learning" science often encompasses an initiate–response-evaluate exchange (i.e., IRE; Cazden, 1988; Lemke, 1990) between the teacher and students. Through these triadic conversations, the teacher's role is to be the arbiter, addressing and validating students' ideas (Lemke, 1990; Michaels & O'Conner, 2017), and the desired objective of articulating the "right answer" leaves little room for multiple student perspectives to be heard and disputed (Scott, Mortimer, & Aguiar, 2006). Yet, argumentation encompasses students grappling with uncertainty (Manz, 2015) as they work together to produce and critique competing claims about scientific phenomena (Berland, McNeill, Pelletier, & Krajcik, 2017). Thus, "doing" science through argumentation inherently involves interactional patterns among students that are unlike those that prevail in science classrooms.

Although student use of an argument's structural features has been studied in many ways (e.g., Monteira & Jiménez-Aleixandre, 2016; Sadler, 2004; Sandoval & Millwood, 2005), these analyses do not fully capture the highly interactive aspects of this science practice, which include the actions students perform while constructing arguments and persuading their peers about the strength of a particular claim (M. Ford, 2008). To help teachers and students transform classroom discourse practices toward including argumentation, more research is needed around how to support students in the processes of this science practice (Andriessen, 2007). Several methods have been used to analyze argumentation (Erduran, 2008), but it is essential to identify analytic techniques that capture the complex, social dimensions of this practice. Furthermore, to be consistent with perspectives of discourse practices as social phenomena (Bakhtin, 1981; Gee, 2012) the analysis ought to be focused at the level of the interaction as opposed to the individual (Wagner & González-Howard, 2018). Toward this end, I propose social network analysis (SNA), a methodology focused on social relations between entities that can make visible the interactional patterns among individuals in a network, such as students in a classroom (Carolan, 2014). This exploratory study delves into the utility of this analytic approach for shedding light on and investigating, a classroom community's discourse patterns while engaged in argumentation. Specifically, this study was guided by the question—*How can SNA be used to visualize the interactional nature of argumentation discussions?*

2 | THEORETICAL FRAMEWORK

2.1 | Scientific argumentation

Many analytical frameworks have been used to evaluate how a class engages in argumentation (Henderson, McNeill, González-Howard, Close, & Evans, 2018; Sampson & Clark, 2008). Argumentation encompasses structural and dialogic components (Jiménez-Aleixandre & Erduran, 2008; McNeill, González-Howard, Katsh-Singer, & Loper, 2016), both of which are critical to how students "do science" through this practice. Students can frame their new, or working, understanding of natural phenomenon through the three structural elements that make up an argument: a claim, evidence, and reasoning (McNeill, Lizotte, Krajcik, & Marx, 2006). Specifically, a claim is a conclusion about a problem; evidence comprises scientific data (i.e., accurate measurements and observations) that are 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). Unlike prior work that mainly examined the structural pieces of students' arguments (i.e., whether students articulated reasoning; McNeill et al., 2006), the current study also takes into account how these structural pieces are *used*—the ways that students include, ignore, and debate claims, evidence, and reasoning during argumentation discussions. In terms of the dialogic component, argumentation also entails students evaluating and debating the strength of a particular argument with others, as well as the revision of arguments (M. Ford, 2008; M. J. Ford, 2012). Student participation in these processes is driven by goals of engaging in critique (Henderson, MacPherson, Osborne, & Wild, 2015), persuasion, and sensemaking (Berland & Reiser, 2011).

Although described as two different aspects, 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. As students engage in these interrelated components they develop and improve upon their understandings of natural phenomena (Berland et al., 2017).

Considerable research on argumentation has focused on the structural makeup of students' arguments, such as whether students understand what counts as evidence (e.g., Sadler, 2004), or if students sufficiently justify their claims (e.g., Sandoval & Millwood, 2005). Learning to include these features can be a productive starting point; however, to meaningfully engage in argumentation, students need to move beyond addressing the structural features of an argument (M. J. Ford, 2012). Although some research has examined the extent to which classroom communities support argumentation (e.g., Berland & Reiser, 2011; Duschl & Osborne, 2002; González-Howard & McNeill, 2016), fewer studies have synthesized teachers and students' interactions while engaged in this science practice (e.g., Manz, 2016; McNeill & Pimentel, 2010). Consequently, research is needed that accounts for both aspects of this science practice.

2.2 | Analyzing argumentation in the science classroom

2.2.1 | Methodological approaches used to study argumentation

The methods utilized to evaluate argumentation in classroom instruction vary depending on the theoretical frameworks researchers use to understand this science practice, as well as the focus of the researchers' work (Erduran, 2008; Henderson et al., 2018). Sampson and Clark (2008) categorized and described prior methodological approaches under three different issues commonly studied: (a) the structural components of an argument, (b) the content of an argument, and (c) the nature of how students justify arguments. Moreover, they noted that while there are affordances to each of these foci and their corresponding analytic techniques, there are also constraints (Sampson & Clark, 2008).

For instance, a popular approach to examining students' arguments has been through adaptations of Toulmin's (1958) argument pattern (TAP; e.g., Jiménez-Aleixandre et al., 2000; Kulatunga, Moog, & Lewis, 2013; Zohar & Nemet, 2002). The TAP method focuses on how students organize the structural features of an argument, particularly in terms of the following elements: claim, warrants, qualifiers, backings, and rebuttals. For example, Erduran, Simon, and Osborne (2004) applied the TAP scheme to small and whole group discussions in middle school science classrooms. This approach enabled them to explore changes in the quality of students' arguments over an extended period of time. Yet, depending on the length of students' arguments, issues have arisen with respect to coding the different elements encompassed within TAP (e.g., differentiating a claim and a warrant; Kelly, Druker, & Chen, 1998). Focusing on the presence and absence of structural features also provides less insight into the accuracy and content in arguments (Sampson & Clark, 2008). Additionally, given how laborious the TAP methodology is to carry out, it is difficult to adapt to large-scale studies (Erduran, 2008).

Other research, which has analytically ranged in grain size from small groups (e.g., Ryu & Sandoval, 2015; Sampson & Clark, 2009) to whole class argumentation (e.g., Engle, Langer-Osuna, & McKinney de Royston, 2014; Marco-Bujosa, McNeill, González-Howard, & Loper, 2016), has explored the collaborative nature of this science practice. By iteratively coding instances during which students engage in an argumentation task, much of this study has identified various types of argumentation interactions. For example, through this approach, Evagorou and Osborne (2013) characterized pair discussions with discourse codes such as "exploratory talk," which included instances of students discussing a peer's ideas, and "dispute talk," which captured whether a student challenged another's argument. These different discourse moves were then presented in the findings through portions of students' conversations that had been transcribed and annotated. Similarly, González-Howard, McNeill, Marco-Bujosa, and Proctor (2017) coded videos of whole class argumentation in terms of students' interactions (e.g., critiquing an argument produced by a peer, or asking another student a question) and illustrated the findings through histograms that broke down the percentage of talk that encompassed these moves. Although important in addressing the dialogic component of students' argumentation, these analyses paint a broad picture of this science practice, primarily describing various types of interactions as either having taken place or not. Also, these analyses do not delve into the particularities of interactions, such as whether students are critiquing each other's evidence or evaluating peers' reasoning. Such information could offer rich insight into students' argumentation practices, which would enable teachers to better tailor their instruction to meet the specific needs of their students. Additionally, prior approaches have not examined or portrayed patterns of social communication between classroom members during argumentation tasks. It is important to identify and analyze these discourse patterns, so as to develop deeper understandings of the ways students work together to construct and critique arguments (Henderson et al., 2015).

2.2.2 | Visualizing argumentation interactions

A handful of studies have documented patterns in classroom communication by creating visualizations of the complex ways that students engage in argumentation. Some of this study has coupled information about the role of the contributor (e.g., teacher or student) with the content of their contribution. For example, interested in studying student participation, Maloney and Simon (2006) constructed "Discussion Maps" of students' argumentation. Their mapping technique provided a visual way of evaluating how students reviewed evidence and iteratively discussed arguments, ignoring certain pieces of evidence and pursuing others. This approach also enabled researchers to see which students were involved in the discussion, which allowed them to examine how students' participation varied across activities. Similarly, Hogan, Nastasi, and Pressley (1999) created "Discourse Maps" to compare and contrast small group discussions with and without teacher guidance around explanatory models that students developed using evidence from class experiments. The discourse maps captured the chronological order of three statement types during the discussions: conceptual (e.g., a student presents an idea), questions (e.g., a student responds to a query from a peer), and metacognitive (e.g., a student reflects on their lack of understanding about the material being discussed). Additionally, these maps illustrated the sequence of teacher and student moves. Even more fine grained in the level of detail included in their mapping of student discussions, Resnick, Michaels, and O'Connor (2010) analyses had visual features, such as varying shapes and links, that represented different types of argumentation moves (e.g., a concession, a challenge, or answer to a challenge). Although insightful, in a practical sense these diagrammatic techniques are limited in that even short argumentation transcripts result in numerous pages of maps, which are not easily discernible. Thus, these visualizations do not allow for a quick snapshot of which classroom members were involved in this science practice and in what ways.

2.2.3 | SNA of argumentation

A particularly informative, and recent, approach for studying student participation in argumentation discussions has been through SNA, a methodology that examines various types of relations, and patterns of these relations, among entities (Borgatti & Ofem, 2010). For instance, Yoon (2011) explored the visualization affordances of SNA, using sociograms—images of social relations in a network—that illustrated patterns of students' interactions as an intervention for improving group-level processes and learning outcomes. Handheld electronic devices archived participants' interactions during a series of different paired discussions and were used to create sociograms of the communication network in the classroom. Students were shown the sociograms and provided with questions to scaffold observations of their interactions (e.g., To whom have you spoken with most consistently over time and why?). Findings indicated that after viewing the sociograms, students' rules about who to talk to during argumentation activities shifted from nonreflective (i.e., friends) to reflective (i.e., peers with differing opinions), and subsequently that their understanding of the science ideas being explored became deeper and more complex.

Most recently, Ryu and Lombardi (2015) used SNA to examine how an experienced third/fourth grade science teacher intentionally attempted to encourage less engaged students to participate during argumentation discussions by assigning and rotating different roles and responsibilities. Employing SNA allowed the researchers to illustrate how students' individual and collective engagement increased over time. For instance, using sociograms, the researchers showed how one particular student, an English language learner, who was often in the periphery of group discussions became more central later in the school year as he gained comfort working with peers. However, similar to the Yoon (2011) study, this study explored student participation generally (i.e., the extent to which students talked to peers), and did not tease apart the substance of students' exchanges in terms of argument structure and dialogic interactions.

The current study builds on both earlier research around students' argumentation and prior research that has used SNA for studying student interactions. By combining these two areas, this study intends to address the areas of need described above. Specifically, this study considers how sociograms derived from SNA can be used to accomplish two tasks: first, to illustrate interactions during argumentation in terms of each component of this practice (e.g., Who references evidence in their contributions, and to whom are they directing this evidence? Who asks questions, and to whom?); and second, to show these interrelated components simultaneously (e.g., Who asks questions *about* evidence, and to whom?). This information can be used in part to form rich descriptions of teacher and student argumentation practices.

3 | METHODS

3.1 | Participants and curricular context

This study used data from a larger project in which teachers piloted middle school science curricula that included a focus on argumentation (see Marco-Bujosa et al., 2016; McNeill, González-Howard, Katsh-Singer, & Loper, 2017 for information about teachers' backgrounds and prior experiences with argumentation, student demographics, etc.). Teachers piloted two units: *Plate Tectonics* (Regents of the University of California, 2012), which concentrated on how features and events on Earth's surface are caused by the movement of plate tectonics, and *Metabolism* (Regents of the University of California, 2013), which focused on how the human body produces energy at the cellular level. For this piece, I draw upon data from two teachers' classrooms: Ms. Allen (all names are pseudonyms) taught the *Plate Tectonics* unit to her sixth grade students, and Mr. McDonald piloted the *Metabolism* unit with his seventh grade students.

Each unit concluded with a science seminar: A whole class activity designed to elicit argumentation 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 that were arranged in two concentric semicircles. Students sitting in the inner semicircle (i.e., Group 1) debated the science seminar's question first, whereas those in the outer semicircle (i.e., Group 2) listened actively and completed an observation sheet. Halfway through class, the groups switched. In terms of argumentation, this activity encompassed both components of this science practice: Students engaged in dialogic interactions (e.g., questioned one another) while they constructed and refined their understanding of the focal phenomena as framed through the structure of an argument (e.g., explained how evidence supported a claim).

Specifically, the science seminar for the *Plate Tectonics* unit was guided by the question: How will the Indian Plate be different in 50 million years? In preparation for the activity, students were given a map that contained the Indian Plate and information about its surrounding plate boundaries including collision, spreading or subduction zones, nearby active volcanoes, and arrows indicating the direction plates are moving. Meanwhile, 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? Before the science seminar, students had been divided into three groups, each of which were given data from studies about bodies' responses to exercise (e.g., increases in lung capacity). For both of these units, analyzing these data enabled students to construct and debate multiple claims.

3.2 | Data source

Both classrooms were split into two groups during the science seminar lesson, each of which had an opportunity to engage in the argumentation activity (see Section 3.1 for details). This resulted in the analysis of four discussions: two from Ms. Allen's class and two from Mr. McDonald's class. Each science seminar was video recorded and transcribed in its entirety. In addition to the verbal remarks made by the teachers and students, transcripts also included nonverbal cues. These nonverbal contributions (e.g., student points to a data table when disagreeing with a peer's argument or the teacher nudges a student's shoulder prompting them to speak) were important for understanding the interactions among classroom members during the argumentation discussion.

3.3 | Data analysis

3.3.1 | Overview of SNA

SNA offers a means by which to examine, quantify, and visualize relations between actors in a network. In the current study, SNA was used to examine a particular type of relation: Interactions, which are "typically conceptualized as [observable] discrete events that can be counted over a period of time" (Borgatti & Ofem, 2010, p. 20). The interactions explored were those that occurred between the students and teachers in the focal classrooms as they engaged in argumentation during the science seminar activity. Identifying and analyzing these interactions led to the creation of sociograms–diagrams consisting of nodes that represent actors, and ties that symbolize relations among actors (Carolan, 2014; Katz, Lazer, Arrow, & Contractor, 2004). In the sociograms created as part of this study, the nodes were either teachers or students and the ties captured different exchanges between individuals in terms of both the structural and dialogic components of argumentation.

The sociograms (see Section 4) showed various aspects of the science seminars, such as whether particular types of interactions occurred between all actors or whether some actors were engaged more, or less, with other group members (Haythornthwaite, 2002). Sociograms also highlighted individuals who were positioned in certain ways during the discussions, including people who were at the periphery, central actors, and individuals who served as bridges between some participants and the rest of the class.

Many steps were taken to prepare the science seminar transcripts for the SNA to create sociograms that captured the interactional nature of the focal classrooms' argumentation discussions. These steps included: breaking the transcripts into utterances; coding the utterances across argument structure, dialogic interactions, and ties; and creating valued, directed matrices. Each of these steps is described in the following subsections.

3.3.2 | Breaking the transcripts into utterances

Similar to the work of other researchers who have examined oral argumentation (e.g., McNeill & Pimentel, 2010), in preparation for analysis, the transcripts for each science seminar were broken up into utterances. An "utterance" was operationalized as an idea or contribution to the discussion. Ideally, each utterance captured an argumentation component (i.e., a structural feature of an argument, a dialogic interaction, or a combination of both). However, sometimes utterances were unrelated to argumentation (e.g., a student asked an off-topic question). Depending on the number of ideas included in a turn of talk, an individual's turn could include one or multiple utterances. For example, in one student's turn during a science seminar in Ms. Allen's class (in which students debated the location of the Indian Plate in 50 million years), the student said, "I just don't think India would just slide past the Eurasian Plate./They've been colliding and making the Himalayan Mountains for millions of years." This turn was coded as encompassing two utterances, separated by the/in the previous sentence. Two raters independently broke 20% of each science seminar transcript into utterances, obtaining 91.3% interrater reliability in the process.

3.3.3 | Coding the utterances across argument structure and dialogic interactions

Each utterance was coded across two different coding schemes—one focused on argument structure and the other on dialogic interactions during the argumentation activity. This coding process was essential for operationalizing the different types of argumentation-related interactions that were examined in this study. Specifically, the coding schemes used in this process were developed from both the theoretical framework of

TABLE 1 Synthesized coding scheme for argument structure

Codes	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 (measurements or observations that are either firsthand or secondhand) that either support or refute a claim	"Study 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 thought the same thing as her."

TABLE 2 Synthesized coding scheme for dialogic argumentation

Codes	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 discussion	"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 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."

scientific argumentation and iterative analysis of the science seminar transcripts (Miles, Huberman, & Saldaña, 2013). Tables 1 and 2 include a synthesized version of both coding schemes. The examples for each code were obtained from Mr. McDonald's students, who enacted the science seminar from the *Metabolism* unit (see Section 3.1 for details).

The coding scheme for argument structure (see Table 1) was informed by McNeill and Krajcik's (2012) claim–evidence-reasoning framework, which has been used often to study and evaluate students' arguments (e.g., Marco-Bujosa et al., 2016; McNeill & Pimentel, 2010). Utterances 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 to someone voicing an off-topic comment to students discussing ideas that were tangentially related to the science seminar's guiding question. The latter occurred most often when this code was assigned. Although not explicitly related to argumentation, it was important to also capture these types of utterances to fully understand the types of ideas students discussed when engaged in this science practice.

Thus, each utterance was classified under one of four possible argument structure codes. Two raters independently coded 20% of each science seminar transcript for argument structure and obtained 96.9% interrater reliability.

Additionally, each utterance was analyzed in terms of the dialogic interactions between classroom members throughout the science seminar activity. The development of the coding scheme used to accomplish this task was informed by research describing social exchanges that take place during argumentation; specifically, as detailed across the work of M. Ford (2008), M. J. Ford (2012), and McNeill et al. (2016, 2017). In terms of dialogic argumentation, utterances not captured by the code for questioning, critiquing, or building on other's ideas received a code of "Other." Utterances coded as "Other" tended to occur when students read aloud their written arguments from their notebooks, without making connections to peers' prior contributions.

Each utterance was categorized under one of four possible dialogic argumentation codes (see Table 2). Two raters independently coded 20% of each science seminar transcript in terms of dialogic interactions, obtaining a 92.3% interrater reliability. Any disagreements that arose during the coding process were resolved through discussion.

It is important to reiterate that because the structural and dialogic components that make up argumentation are synergistically related, each utterance from the science seminars was coded across both coding schemes. For an example of what this part of the analysis looked like, see the coded transcript in Table 3, which was taken from Mr. McDonald's Group 1's *Metabolism* science seminar (refer to corresponding coding schemes in Tables 1 and 2).

TABLE 3 Sample coded transcript from Mr. McDonald's Group 1

Turn, timestamp, and speaker	Contribution (/utterance/)	Structure code	Dialogic code	Ties
Turn #26, [36:20], Student 6	I had a question for Student 7. /Umm how come like we said that athletes like their lungs get that their lungs expand so they can like run fuller distances. /Sometimes like healthy people jog and like run for like exercise. /How come do their lungs expand and get bigger? /Or just athletes?	Other Claim Other Other Other	Other Other Other Questioning Questioning	Student 6 → Student 7
Turn #27, [36:39], Student 7	Well, your lungs expand with each like breath that you take. /But when you when you're consistently exercising, you're releasing a lot of energy and that helps growth and repair. /Umm like energy helps growth and repair and that growth helps build up the muscles.	Reasoning Reasoning Reasoning	Building Building Building	Student 7 → Student 6
Turn #28, [37:00], Student 9	And those people might not also be necessarily athletes /cause the athletes in the studies were considered people who studied for who umm–	Other Evidence	Building Building	Student 9 → Student 7
Turn #29, [37:10], Student 6	Exercised like 10 hr	Evidence	Building	Student 6 → Student 9
Turn #30, [37:11], Student 9	Exercised for like 10–15 hr a week.	Evidence	Building	Student 9 → Student 7

3.3.4 | Coding the ties

Once utterances were coded across both argument structure and dialogic interactions, the ties between turns of talk during the science seminar (i.e., who was talking to whom) were determined. The last column in Table 3 notes the ties between classroom members; these were necessary to track to conduct the SNA. Although all participants may hear any contribution during a group discussion, a turn is typically taken to respond to a specific individual in the group. As such, the following sources were used to identify the recipient of a turn: (a) following who talks after whom, (b) reading the content of a response, and (c) 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. Again, two raters independently coded 20% of each science seminar transcript in terms of ties and achieved 86.9% interrater reliability. The few disagreements that came up when coding for ties were resolved by revisiting the videos of the science seminars, and through discussion.

3.3.5 | Creating valued directed matrices

After the transcripts were coded, valued and directed matrices (Carolan, 2014) of argumentation ties for both the structural and dialogic contributions from each science seminar were created. The term "valued" refers to the extent to which a tie between two actors did or did not exist (e.g., 7 = *seven questioning utterances made toward a person*, 0 = *no questioning utterances made toward a person*), whereas the term "directed" refers to whether the comment was reciprocated. Further, valued and directed matrices were also created that cut across the components (e.g., questioning utterances *around* reasoning) to explore the intersections of these aspects of argumentation. The dimensions of each matrix consisted of students in a group and the teacher, with each actor represented by both a row and a column.

3.3.6 | Carrying out the SNA and creating sociograms

These matrices were then inputted into UCINET 6 (Borgatti, Everett, & Freeman, 2006) software, which is designed specifically for analyzing social network data. This software program includes NetDraw, a visualization tool with advanced graphing features. NetDraw utilizes optimization algorithms, some of which draw upon multidimensional scaling, to create diagrams that are esthetically easy to read (Borgatti, Everett, & Johnson, 2018). For instance, one of the optimization criteria that NetDraw follows is a preference for equal length ties, which results in sociograms having a layout that makes symmetry easier to identify among the relations of interest. A drawback of NetDraw's optimization algorithms is that the physical distance between nodes does not hold meaning, in a mathematical sense (i.e., the closeness between two nodes does not necessarily imply a stronger relationship between those nodes). However, because SNA focuses on the relations among entities, the sociogram layouts are meaningful in that they contain information about the connections between nodes, including the existence and strength of these connections (Borgatti et al., 2018).

The underlying goal of this study was to explore how SNA could be used to visualize various aspects of the interactional nature of argumentation discussions. Therefore, for this study, UCINET 6 software—more specifically, the NetDraw feature—was used to create sociograms that shed light on the interactional patterns during the science seminars across the structural and dialogic components of argumentation. Numerous sociograms were created for each discussion. Some of these focused on one type of argumentation tie of interest (e.g., critiquing *or* evidence), whereas others which cut across the structural and dialogic components of this science practice (e.g., critiquing *around* evidence). Among other sociograms, for each discussion, one sociogram was created that cut across all structural codes, one that cut across all dialogic codes, and one that portrayed general participation. The sociogram for general contribution was created to examine what is captured and lost by evaluating student engagement with this lens alone. This analysis resulted in a total of 72 sociograms (18 for each group's seminar), a subset of which are discussed in this paper. The sociograms in this piece were selected based on their utility in highlighting the affordances and limitations of using SNA to examine the interactional nature of argumentation discussions.

4 | FINDINGS

The main objective of this study was to explore the utility of SNA for visualizing teacher and student interactions while engaged in scientific argumentation. The findings are presented in two sections. The first section provides an overview of the focal classrooms' science seminars, offering general information about each argumentation discussion, such as the breakdown of teacher and student contributions. This information grounds the second section of the Findings, in which various aspects of the argumentation discussions from Ms. Allen and Mr. McDonald's classrooms are represented via sociograms derived from the SNA. The second section highlights a subset of sociograms from the two classes, illustrating ways in which SNA can shed light on discursive patterns between individuals engaged in scientific argumentation. The manner in which these sociograms are presented is intended to show possible ways that this approach could be used to compare and contrast argumentation practices in one classroom, or across classrooms.

4.1 | Overview of the science seminars

There are a few ways that the focal classrooms' science seminars were similar and different. In this section, I describe the four argumentation discussions, providing information about the duration, number of turns of talk and utterances, as well as the breakdown of teacher and student contributions during each group's seminar. The discussions are also compared in terms of occurrence of the structural and dialogic components of argumentation (e.g., percentage of utterances coded as questioning or evidence). Table 4 offers a glimpse into the four argumentation discussions. As seen in Table 4 the discussions varied in length, averaging 12 min. Although the shortest science seminar lasted 9 min and 16 s (Group 1 in Ms. Allen's class), students spoke for 17 min and 53 s during the longest science seminar (Group 2 in Ms. Allen's class). The frequency of contributions was wide-ranging, with Mr. McDonald's Group 2 having the least number of turns of talk, and Ms. Allen's Group 2 having the most turns of talk.

Given that the discussions in Mr. McDonald's class were not noticeably shorter than the average length of the seminars across the two classrooms, the fewer turns during his students' debates stood out. However, in examining the transcripts from this class more closely, it became clear that this was due to his students' turns of talk being longer in duration, often including multiple utterances. Additionally, out of all the argumentation discussions, Ms. Allen's Group 2 had the most utterances, whereas Mr. McDonald's Group 2 had the least.

TABLE 4 Breakdown of the science seminars

Teachers	Group	Duration	Turns	Utterances
Mr. McDonald	Group 1	10 min, 33 s	56	134
	Group 2	9 min, 34 s	42	113
Ms. Allen	Group 1	9 min, 16 s	114	205
	Group 2	17 min, 53 s	119	269

4.1.1 | Classroom member contributions

Figure 1 illustrates the breakdown of utterances across classroom members in the two classes. Overall, students were observed contributing most during the activity, averaging 81% of the total utterances across both classrooms. This suggests that the students primarily carried out the argumentation discussion, with the teachers speaking minimally. Had the seminars followed more traditional whole class discourse patterns (e.g., IRE; Cazden, 1988; Lemke, 1990), the teachers would have had more utterances. That said, compared with Mr. McDonald, Ms. Allen was more involved during her students' argumentation discussions. Specifically, Mr. McDonald averaged almost 12% of the total utterances, whereas on average, Ms. Allen's utterances made up nearly 27% of the total utterances.

It is important to note that while Figure 1 shows that most of the debates comprised of students' utterances, it does not indicate whether students contributed to the argumentation task equally (i.e., Did all students speak? Did a particular student, or students, dominate the seminar?). Furthermore, Figure 1 does not illustrate to whom comments were directed (i.e., Were students speaking mostly to their peers, to the teacher, or to a combination of both?).

4.1.2 | Dialogic interactions and argument structure

The argumentation breakdown across the groups' seminars for both dialogic interactions and argument structure can be seen in Figures 2 and 3. Figure 2 illustrates how the seminars compared across the dialogic aspects of this science practice (i.e., questioning, critiquing, and building off other's arguments). Recall that each utterance from the seminar was coded across both coding schemes. For example, an utterance such as, "How old were the twins in your study?" received a code of "Questioning" for dialogic interactions, and "Evidence" for argument structure (see Table 1 for additional examples). Overall, there was variation in how the teacher and students in the focal classrooms interacted with each other's ideas. For instance, while Mr. McDonald's seminars included higher instances of individuals building on other's arguments, Ms. Allen's students tended to challenge and critique their peers more often.

Examining Figure 3, one sees that classroom members generally attended to the structural components of an argument (i.e., claim, evidence, and reasoning), although to varying degrees. Yet, differences in argument structure also occurred within the same teacher's classroom. For instance, Group 1 in Mr. McDonald's class discussed reasoning less than Group 2.

The code of "Other" merits a comment, which across all four seminars made up nearly 50% of the total utterances. Although a large percentage of the discussions were comprised of these types of utterances, this is not unexpected. Prior research has documented student challenges when learning to engage in this science practice,

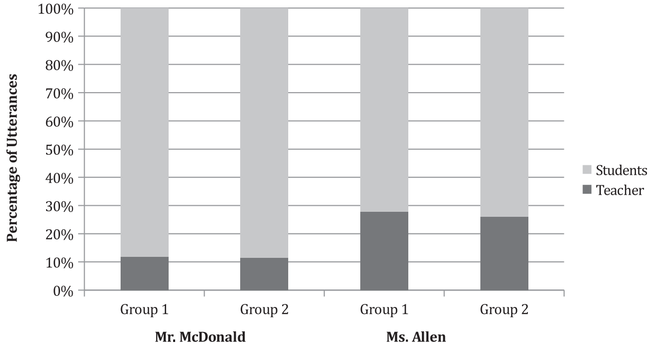

FIGURE 1 Breakdown of utterances across classroom members

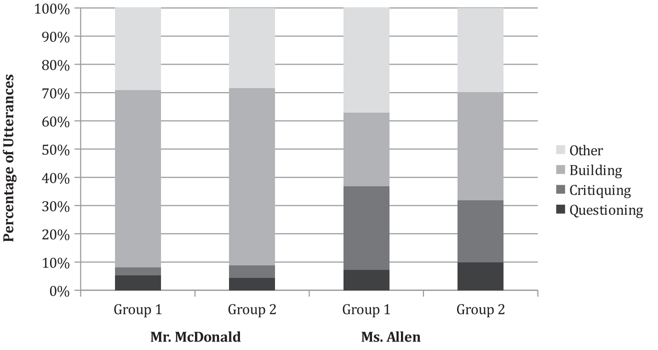

FIGURE 2 Breakdown of utterances across dialogic argumentation codes

even when receiving targeted support around these structural features (e.g., McNeill et al., 2006; Sandoval & Millwood, 2005). As participants in this study were new to argumentation, and the science seminar was students' first opportunity to carry out an argumentation discussion, one would expect them to not address the structural aspects of an argument as much. Additionally, during the science seminar activity, students were doing more than presenting their claim, evidence, and reasoning; they were also working together to build the strongest response to the guiding question, which required them to engage in conversational moves other than those related to an argument's structure.

Table 4 and Figures 1–3 are helpful for identifying commonalities and differences among the seminars in terms of the frequencies of different types of utterances. Through these representations, one can conclude that students primarily led the argumentation discussions, and that to varying degrees students in both classrooms participated in the structural and dialogic aspects of this science practice. Given this information, the following section presents a different way to capture engagement in this science practice, demonstrating how a combination of representations, including sociograms derived from SNA, can paint a fuller picture of a classroom's argumentation experiences.

4.2 | Visualizing interactional patterns through sociograms

This section illustrates the same data through sociograms from the SNA. First, I present and describe sociograms from one group's seminar (Ms. Allen's Group 2), illustrating the insight sociograms offer into the interactions that take place across the structural and dialogic components of argumentation. Then, I bring in sociograms from another group's science seminar (Mr. McDonald's Group 2), to show how this analytic technique can be used to examine variation within and across classes. As noted in Section 3, the sociograms presented here were chosen

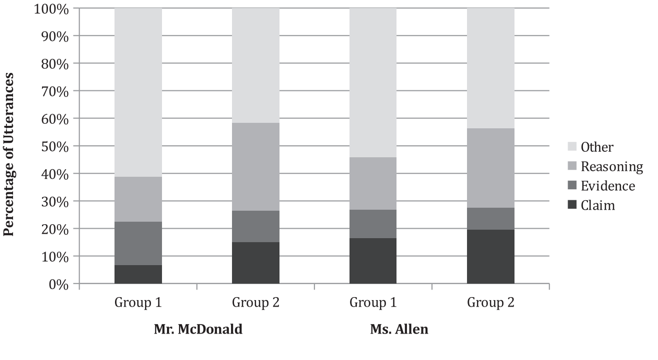

FIGURE 3 Breakdown of utterances across argument structure codes

because of their utility in illustrating the potential of SNA for studying the interactional nature of argumentation discussions.

4.2.1 | Analysis within one group

This subsection provides and discusses a variety of sociograms—starting broadly (e.g., sociogram of all dialogic interactions) and then narrowing the focus (e.g., sociogram of questioning around reasoning)—to illustrate how SNA can be used to visualize and draw attention to particular aspects of argumentation engagement. Recall that the sociograms used to exemplify this utility come from Group 2 in Ms. Allen's classroom.

4.2.2 | Sociograms of general interactions

An outcome of SNA is a sociogram, which consists of a set of nodes along with a set of ties that connect the nodes (see Section 3.3.1 for additional information). In the sociograms from this study, the nodes are either a teacher (represented by a circle) or students (denoted as diamonds), whereas the ties, which may or may not be directional, capture the type of argumentation interaction being focused on (e.g., utterances of questioning). Figure 4 includes the general participation of classroom members during the focal group's science seminar, which included all utterances spoken throughout the science seminar, not just those captured by one of the codes for argument structure or dialogic interactions. These sociograms were generated to obtain an understanding of classroom members' general engagement during the argumentation activity.

In sociograms, the size of nodes varies depending on the number of times an actor was coded as engaging in a particular type of tie, which for Figure 4 is generally speaking during the discussion. In this group's seminar, the least number of times that an individual spoke was zero, whereas the most was 70. A few classroom members clearly stand out as having talked more, in particular, Student 10 and Ms. Allen, who each had 70 utterances. However, given the size of their nodes, it is evident that Students 3, 13, and 14 also spoke frequently during the seminar.

It is also important to examine the ties in a network, which are represented by the arrows between actors. In this sociogram, the ties include information about which classroom members talked to each other during the seminar. Figure 4 illustrates that there were general interactions between all classroom members during this discussion as every individual had at least one tie to them. Ms. Allen and Student 10, in particular, had ties to everyone, signifying that they both made at least one utterance toward all individuals in the group. There were also

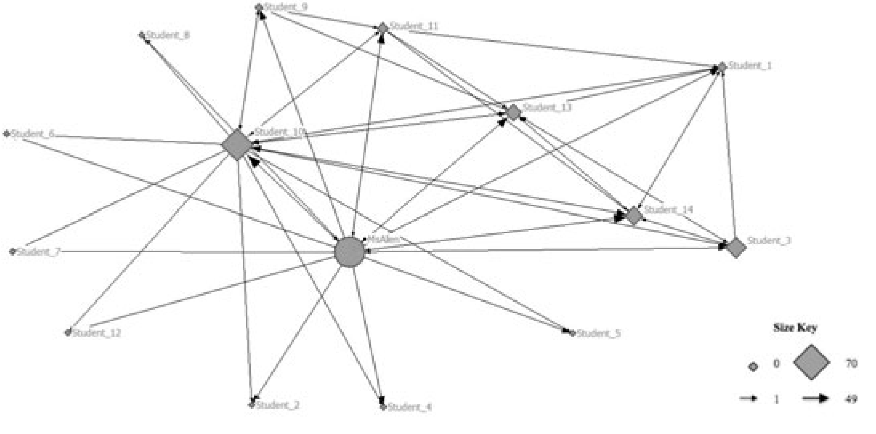

FIGURE 4 Sociogram of general participation in Ms. Allen's Group 2

classroom members who never made remarks to one another during the entire argumentation activity, such as Students 5 and 3, which is apparent by the lack of ties between them. Moreover, while some arrows are double headed (see Students 10 and 14), others only go from one actor to another (see Ms. Allen and Student 2). Similar to the size of nodes, the size of the arrowheads is indicative of the number of times a particular tie was made between actors (see key in Figure 4). Thus, while some individuals only made one utterance to another participant during the debate, others interacted more frequently. Specifically, Ms. Allen stands out as frequently addressing particular students during the activity, such as Students 10 and 13.

The information presented in Figure 4 is akin to that in Table 3 and Figure 1 (general overviews of the teacher and students' engagement in the science seminar). The sociogram of general participation does not indicate certain particularities detailed in Table 1 and Figure 1, such as the duration of each seminar, and the breakdown of the argumentation discussion across teacher and student utterances. However, this sociogram highlights the exact classroom members that participated in the argumentation discussion, providing an additional level of detail.

Although the sociogram of general participation does begin to shed light on who talked during the science seminar, the extent to which they talked, and to whom, this visualization does not provide information about the argumentation that took place, across either the structural or dialogic components. For instance, it does not offer insight into who questioned another person's idea during the debate, or who used evidence. To achieve this level of detail, I now discuss the sociograms created to capture dialogic interactions related to argumentation.

4.2.3 | Sociograms of dialogic interactions

Figure 5 illustrates the dialogic interactions that took place during the second group's science seminar in Ms. Allen's class: When an individual asked a question, critiqued someone's contribution, or built off of another person's idea (utterances that were coded "other" for dialogic interactions were not included).

Such a lens allows for comparisons between the classroom members who generally participated during the science seminar, and those who engaged in the types of discursive moves that are central to argumentation. Looking across Figures 4 and 5, an examination of the size of nodes indicates that similar individuals stand out as having engaged in more dialogic interactions. Student 10 has the largest node, having made 54 utterances that captured the argumentation interactions of interest. Ms. Allen's node, although still large, is no longer equally as dominant as this particular student, meaning the teacher less frequently partook in dialogic interactions related to argumentation. Others also engaged often in these discursive moves, including Students 1, 13, 14, and 3.

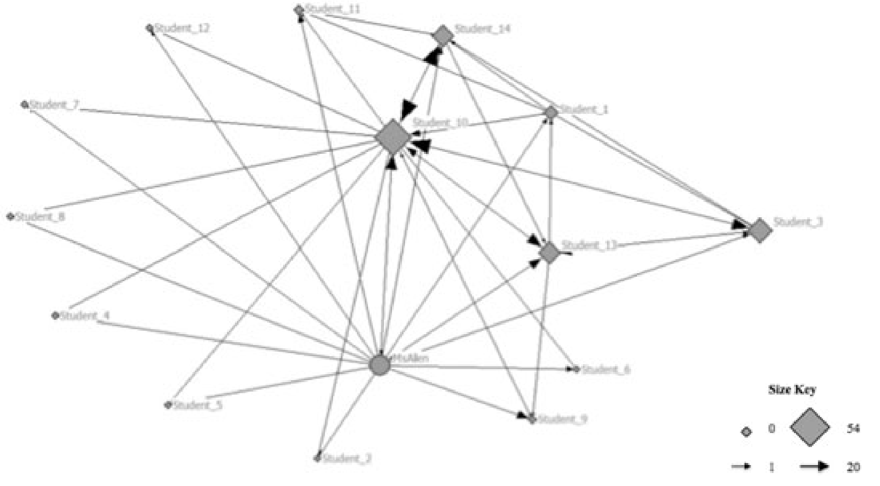

FIGURE 5 Sociogram of dialogic interactions in Ms. Allen's Group 2

Focusing on the ties in Figures 4 and 5, it is interesting to note that in both sociograms, Ms. Allen and Student 10 have ties to all of the participants. Although some of Student 10's dialogic ties were reciprocated, most of Ms. Allen's dialogic ties were unidirectional. This means that students tended not to direct utterances coded as dialogic interactions toward their teacher. Furthermore, as seen by the number of ties and the sizes of the arrowheads, there appear to be numerous dialogic ties targeted toward particular students, especially Students 10. However, other students were also frequent recipients of dialogic ties, including Students 3, 13, and 14.

Although this lens offers more information about the dialogic argumentation that took place during the science seminar of Ms. Allen's Group 2, from Figure 5 alone it is unclear what specific type of interactions occurred (i.e., questioning, critiquing, or building on other's ideas) between classroom members. For instance, we do not know if the dialogic ties between Students 10 and 3 mainly encompassed these students critiquing one another, or asking each other questions. Consequently, I now hone in more on one of these interactions.

4.2.4 | Sociograms of questioning

Figure 6 illustrates the questioning that took place during the focal group's discussion. Specifically, this sociogram provides insight into who asked questions during the science seminar, as well as who was the subject of the questioning.

Similar to the other sociograms discussed thus far, Ms. Allen and Student 10 were dominant actors, evidenced by the size of their nodes (both participants had 10 utterances coded as "Questioning"), as well as the number of ties they have radiated from their nodes (both asked at least one question to every other individual). Examining this sociogram alongside the one previously presented is also informative. For instance, from the sociogram in Figure 5 we know that Student 10 produced 54 utterances that were coded as dialogic ties. Given the information in Figure 6, it is now clear that 10 of these ties included Student 10 questioning their peers, which means the other 44 utterances were "Critiquing" and/or "Building". This sociogram also shows that overall, students in this group did not often question other's ideas during their seminar.

Yet, this representation alone does not portray how much of the discussion included "Questioning". However, from Figure 2 we know that 10% of all the utterances during this argumentation discussion were coded as "Questioning." Combining this information with that provided in the sociogram in Figure 6, it becomes clear that most students (specifically 10 of 14) were recipients of questions, but themselves did not ask any. Another limitation of this particular sociogram is that it does not specify the content of students' questioning. For instance, did the questions during Group 2's discussion revolve around the claims students were making or the evidence and

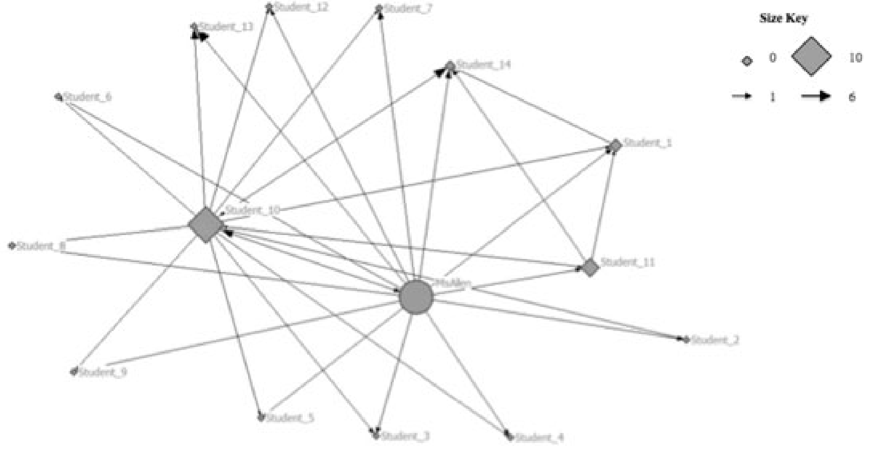

FIGURE 6 Sociogram of questioning in Ms. Allen's Group 2

reasoning they were using to substantiate their arguments? Figure 7, discussed in the following section, demonstrates this level of detail, specifically in terms of questions students posed around their peers' reasoning.

4.2.5 | Sociograms of questioning around reasoning

Figure 7 illustrates how members of Ms. Allen's Group 2 asked questions pertaining to reasoning during the science seminar. This sociogram is a bit different from the others discussed thus far, mainly because fewer individuals offered questioning utterances around reasoning, or had an utterance that contained this type of tie to them. These individuals, who make up two-thirds of the student participant group, are listed on the top left corner of the sociogram. From Table 4, we know that Ms. Allen's Group 2 made 269 utterances during their argumentation discussion, 29% of which were coded as "Reasoning" (see Figure 2). Combining this information with that offered through the sociogram in Figure 7, conclusions can be drawn about which individuals were responsible for providing reasoning ties: Specifically, ties that were coupled with instances during which students asked one another questions. Again, this type of deduction points to the advantage of using SNA alongside other forms of representation.

Compared with Ms. Allen's involvement with questioning generally (see Figure 6), it becomes evident that she asked fewer questions around reasoning. This insight could be informative for follow-up analyses investigating the components of argumentation (if any) that were supported by the types of questions the teacher was asking.

4.2.6 | Summary

Each of the sociograms discussed in this section provided a more nuanced description of Ms. Allen's Group 2's science seminar interactions than the one before it. Figure 4 showed who generally participated in this activity. Figure 5 offered information about classroom members' dialogic interactions. However, given the grain size, it was unclear exactly which discursive moves the students and Ms. Allen engaged in. The focus was then sharpened more with the sociogram of questioning in Figure 6, and even further with the sociogram of questioning around reasoning in Figure 7. As demonstrated thus far, sociograms can be used to illustrate who engaged in the argumentation discussion, and how—information that cannot be obtained from bar graphs alone (i.e., Figures 2 and 3). Although this zooming in is a strength, the tradeoff is losing the perspective of how a particular aspect of argumentation engagement (e.g., questioning) relates to other components of this science practice (e.g., critiquing). However, merging the information offered by different representations (e.g., Figures 2–7) provides greater insight into how individuals partook in the science seminars.

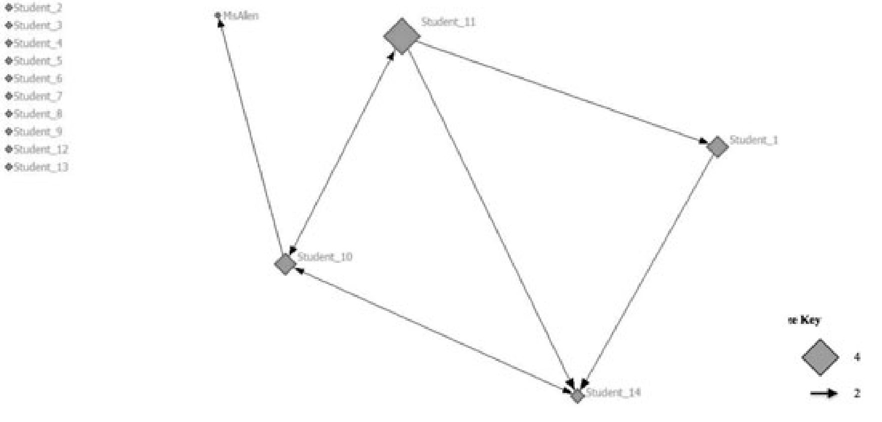

FIGURE 7 Sociogram of questioning around reasoning in Ms. Allen's Group 2

A similar process as the one taken to create Figures 5 and 6 could be used to examine interactions associated with using argument structure. Specifically, sociograms could be produced to consider the multiple structural elements together (e.g., students directing utterances that include claim, evidence, and reasoning) or these elements individually (e.g., students directing utterances around evidence). Although doing so in the current piece would be considered redundant methodologically, it is important to note that SNA techniques could be used to investigate such aspects of students' argumentation.

4.2.7 | Variation within and across classrooms

To explore additional ways in which SNA could be used to visualize and examine the interactional nature of argumentation discussions, the sociograms from each group's seminar in Ms. Allen and Mr. McDonald's classes were compared with one another. Doing so shed light on similarities and differences across and within classrooms, specifically in terms of the structural and dialogic components of this science practice. This utility of SNA is illustrated using one within-class example and one across-classrooms example.

4.2.8 | Analyzing questioning within a classroom

To demonstrate how sociograms can be used to examine variation within a classroom, I focus on the dialogic interaction of questioning in the context of Ms. Allen's class. Figure 8 encompasses the two sociograms that were created to illustrate how individuals in Ms. Allen's class partook in questioning during the seminars. Similar amounts of these groups' total utterances were coded as "Questioning"; specifically, 7.3% from Group 1 and 10% from Group 2 (see Figure 3 for details).

In both sociograms, Ms. Allen and one other individual (Student 3 in Group 1 and Student 10 in Group 2) were observed asking at least one question to all of the other classroom members. This action is evident in the sociograms by these actors having questioning ties to everyone (which positions them to look like the axle to the spokes of a wheel). Given the size of her node, Ms. Allen was a dominant actor in both groups' seminars with respect to questioning. Also, across both groups, very few students asked questions of their peers. The dearth of questioning ties from and between students points to the role of this teacher in primarily being responsible for asking questions during the argumentation activity. Overall, the interactional patterns for questioning were similar within both seminars in Ms. Allen's class.

4.2.9 | Analyzing reasoning across classrooms

The next example, Figure 9, shows how sociograms can serve to explore variation in different classes. These sociograms illustrate how individuals in Ms. Allen's Group 2 and Mr. McDonald's Group 2 used reasoning during their science seminars.

The amount of "Reasoning" utterances from these groups' discussions were also quite similar. Specifically, 29% of the utterances from Ms. Allen's group contained reasoning, whereas 32% of Mr. McDonald's group's debate included students articulating their reasoning (see Figure 3). However, despite similar amounts of reasoning ties, the groups' interactional patterns around this argument structure code differed. For example, similar to the situation described earlier with regard to students' questioning around reasoning (see isolated actors in Figure 7), there were students in Ms. Allen's Group 2 who never offered reasoning during the seminar, nor were they recipients of a reasoning tie (see isolated actors in Figure 9). In contrast, all of the classroom members in Mr. McDonald's Group 2 were somehow involved with this element of argumentation. Additionally, although fewer individuals articulated reasoning in Ms. Allen's group, those who did, did so with greater frequency than the students in Mr. McDonald's group. Therefore, although these groups' reasoning contributions appeared similar in Figure 2, the manner by which classroom members *used* reasoning was actually quite different.

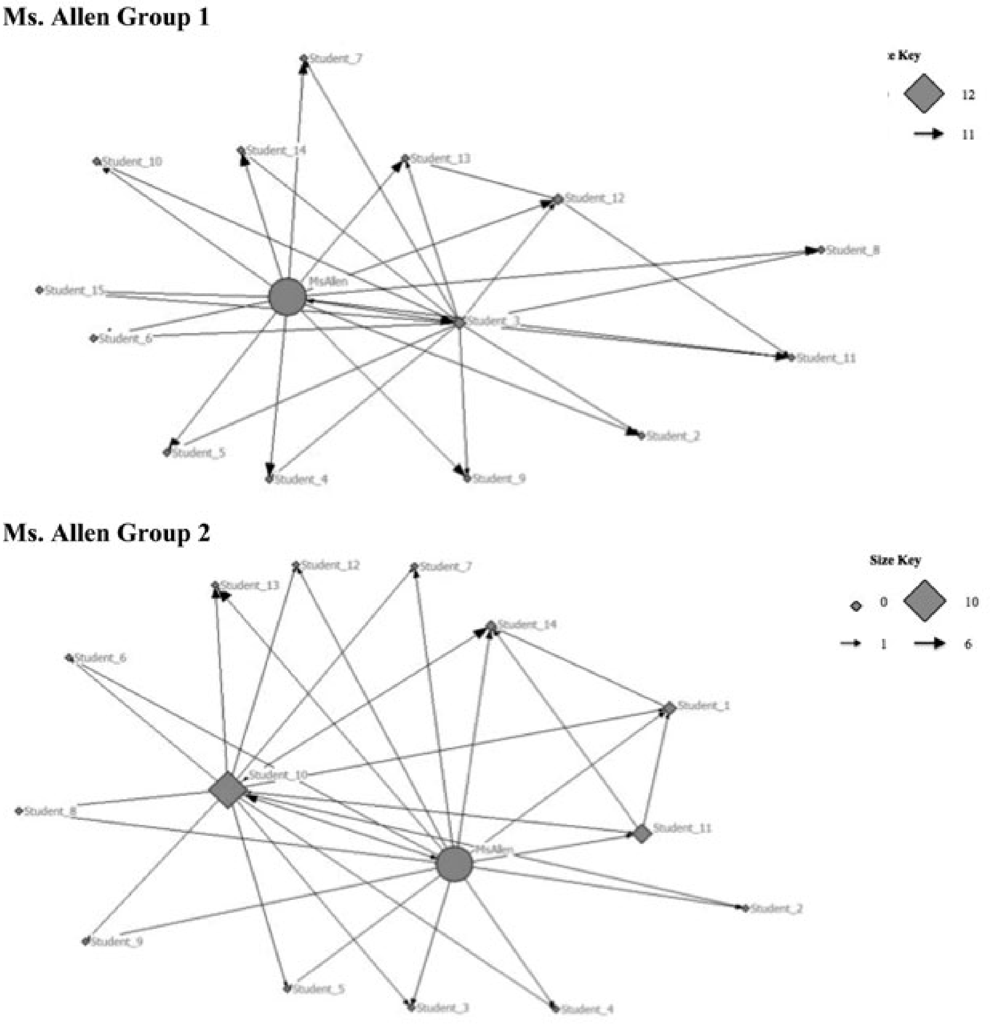

FIGURE 8 Comparing sociograms of questioning within a classroom

These findings illustrate some ways that SNA can be used for visualizing teacher and student interactions while engaged in scientific argumentation, which was the primary goal of this study. Further, the findings revealed how insights obtained from sociograms can be combined with information from other types of representations (such as the bar graphs examined in the first section) to develop deeper understandings of argumentation engagement.

5 | DISCUSSION

Like any methodology, SNA—and the manner by which it was used in this study—has its limitations. Similar to the critique identified by Sampson and Clark (2008) around using the TAP method to evaluate students' arguments, although sociograms highlight the presence of certain components of argumentation (e.g., interactions related to reasoning), they do not address the quality of these components (e.g., the

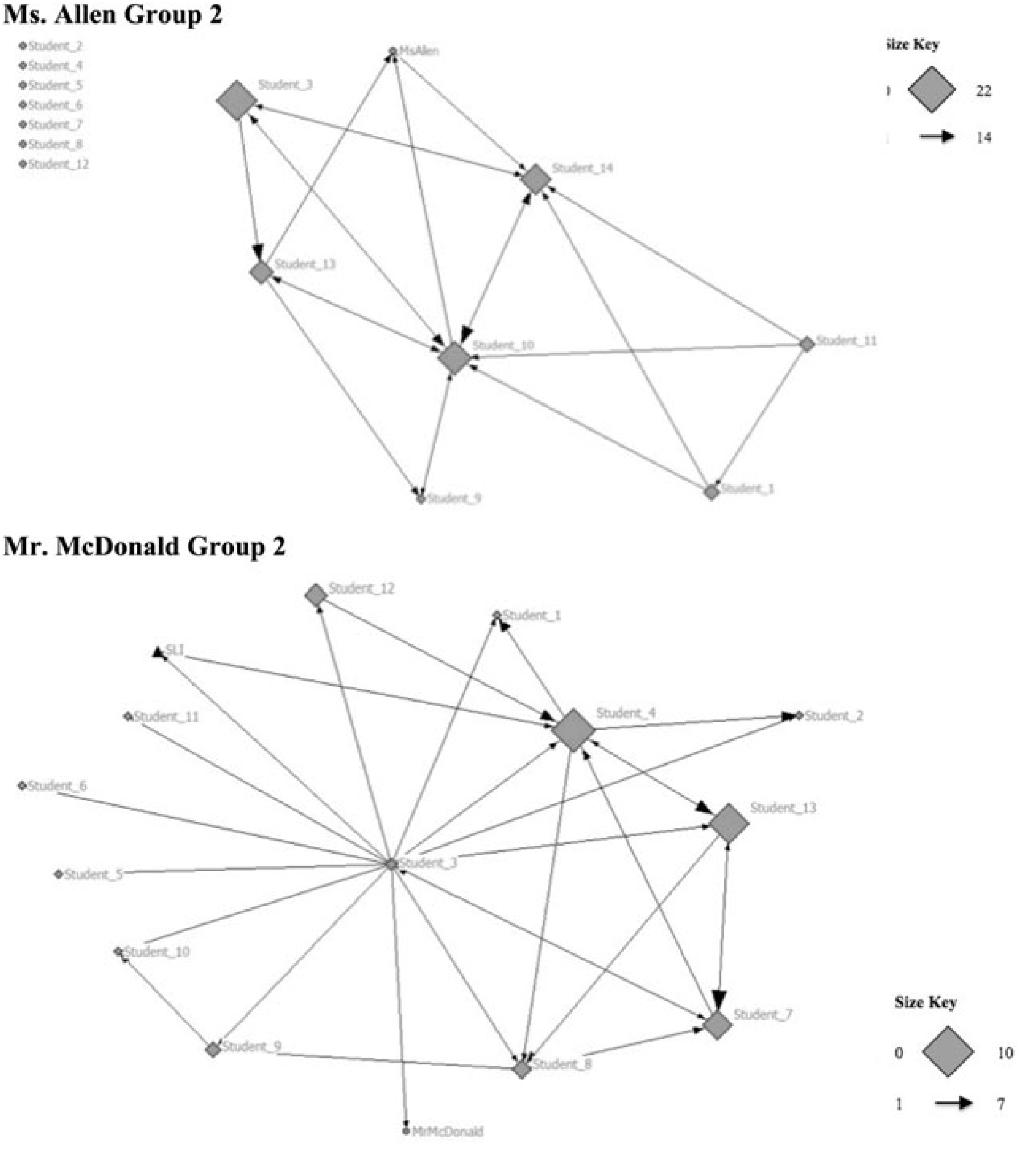

FIGURE 9 Comparing sociograms of reasoning across classrooms

appropriateness of the science ideas students incorporate into their reasoning). However, one could supplement the SNA with other methodologies to richly illustrate particular aspects of this science practice. For example, in a study conducted with the same corpus of data presented in this study, González-Howard and McNeill (2017) used SNA and discourse analysis together to examine critique during these argumentation discussions. Specifically, the SNA was used to shed light on discourse patterns related to instances during which individuals challenged or disputed others' ideas, and also to determine key classroom members partaking in this type of interaction. The sociograms in that study showed general interaction patterns around instances of critique (similar to Figure 6 in this paper). Then, the researchers used discourse analysis to further delve into the language moves these key individuals carried out that encouraged others to engage in critique. Thus, the SNA methods described in this study are capable of standing on their own and of offering insight into the interactional nature of argumentation, but they can be especially valuable when coupled with other analytic techniques and forms of representation.

Another limitation of SNA is that sociograms do not capture the temporal aspects of interaction. Because dynamism is not present in the data, the analysis in this study presents an unchanging view of interactions related to argumentation. For instance, it is plausible to wonder how interactions around questioning might have looked in the second half of the seminar compared with the first half after students started becoming more familiar with their roles and expectations for the argumentation activity. Instead, the sociograms described in this study are snapshots of the argumentation that took place (e.g., Figure 7 which shows overall, how students in Ms. Allen's Group 2 questioned around reasoning during the discussion). These snapshots are valuable, as they enable one to quickly make sense of which classroom members engaged in this science practice and how, information that is not as easy to discern in pages of coded transcripts or discussion maps (e.g., Hogan et al., 1999; Maloney & Simon, 2006; Resnick et al., 2010).

Despite the limitations described above, there were affordances to using SNA to visualize the interactional nature of argumentation during the science seminars. In particular, the sociograms provided insight into how teachers and students participated in the structural and dialogic components of this science practice (e.g., which students discussed reasoning among peers and who were questions being directed to?). With the field striving to transform science education from students "learning" to "doing" science, these findings suggest the importance of argumentation research examining ways to better support changes in classroom interactions. This is especially important to consider as discourse patterns carry strong messages of how students and their teacher are meant to communicate and interact during the learning process. This study also points to the benefits of using SNA along with other types of representations to capture a classroom's engagement in argumentation.

5.1 | Supporting changes in classroom interactions

Researchers whose work has focused on argumentation have long argued for the importance of students learning about how this science practice is fundamental to the ways the scientific community constructs and revises knowledge about the natural world (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002). In addition to developing this understanding, argumentation researchers contend students themselves should have ample opportunities to engage in this science practice (Jiménez-Aleixandre & Erduran, 2008). Partaking in argumentation supports student learning about what counts as strong justifications for a claim (McNeill et al., 2006; Sandoval & Millwood, 2005), as well as how to meaningfully interact with peers to make sense of scientific phenomena (Berland & Reiser, 2011; Henderson et al., 2015). Authentic engagement in argumentation aligns with views of science education that are grounded in students "doing science" (Jiménez-Aleixandre et al., 2000). Reiser et al. (2017) describe the changes associated with students doing science as "a shift from students *learning about* scientific ideas to *figuring out* scientific ideas that explain how and why phenomena occur" (p. 281). Yet, supporting student engagement in this "figuring out" requires a rethinking of the nature of how learning occurs in the science classroom, specifically in terms of the classroom interactions that support students in building their own knowledge (Wilson, 2013).

Developing an understanding of interactional patterns that are inherent to this science practice is important as the student-driven exchanges required by argumentation differ greatly from the interactions that occur during traditional instruction, where students primarily speak to and through the teacher (Lemke, 1990). To meaningfully partake in argumentation, students need to interact with peers to construct and revise arguments and evaluate competing claims (M. Ford, 2008; M. J. Ford, 2012). Without attention to these dialogic interactions, engagement in this science practice could be reduced to students constructing arguments through a formulaic template (McNeill, 2009). Some work in argumentation has examined the interactional patterns during whole class discussions. For example, McNeill and Pimentel (2010) quantified and illustrated patterns between teacher and student utterances (e.g., TS: teacher, student; TSSS: teacher, student, student, student), showing that teachers dominated most conversations, with students infrequently speaking directly to peers.

The sociograms presented in this study not only showed the frequency of each classroom member's contributions, but also who they were interacting with and how. The various types of sociograms discussed in this study, each of which focused on a specific type of tie (e.g., general participation, dialogic interactions, questioning, and questioning around reasoning), shed light on particular aspects of the argumentation activity that would not have been apparent from only reading the transcripts or quantifying the number of different instances. The sociograms illustrated who was involved in the debate, the extent to which they engaged in the discussion, and how they participated in the science seminar. The information offered by examining these discourse patterns is useful for understanding the ways that students are, or are not, interacting among peers to share and discuss these structural elements, each of which plays an important epistemic role in the construction of scientific knowledge. Understanding these interactional patterns can help researchers begin to identify and develop instructional strategies that facilitate changes in classroom discourse norms (Kuhn & Reiser, 2006), which might support shifts toward students "figuring out" (Reiser et al., 2017) science.

5.2 | Benefits of incorporating SNA with other types of representations

Students' argumentation has often been represented through tables and graphs that illustrate particular aspects of their engagement, such as the structural parts that students attend to in written arguments (e.g., Clark & Sampson, 2007), or the presence and quality of students' dialogic interactions (e.g., González-Howard & McNeill, 2016). The first section of this study's findings also used this approach when providing an overview of the focal classes' science seminars across the structural and dialogic components of argumentation (see Figures 2 and 3). This type of representation emphasizes how much of an argumentation discussion is made up of particular aspects of this science practice (i.e., what percentage of the conversation includes students questioning?). Furthermore, it allows for a comparison across different aspects of this science practice (i.e., how does students' questioning compare with their critiquing?). However, like any representation, tables and graphs have limitations. One particular drawback is that they are unable to indicate which classroom members partook in certain aspects of argumentation, and how—information that sociograms are able to highlight, as evidenced in the current study's Section 4. Furthermore, as illustrated in the across-classrooms example, similar percentages do not imply similar discourse patterns. Although Ms. Allen's and Mr. McDonald's Group 2 seminars were similar in terms of the percentage of reasoning utterances, the reasoning sociograms for these groups highlighted differences in how students interacted around reasoning. This would not have been evident when looking at the percentages alone.

Recently, research on argumentation has begun using sociograms derived from SNA to examine general student engagement in this science practice (e.g., Ryu & Lombardi, 2015; Yoon, 2011). This study teased apart student engagement across argument structure and dialogic interactions. Talking across multiple representations of student argumentation (i.e., sociograms and bar graphs) provides a richer description of each classroom's science seminars. The visualization affordances of SNA 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. Thus, in agreement with others (e.g., Clark, Sampson, Weinberger, & Erkens, 2007; Henderson et al., 2018), future research should consider employing SNA, alongside other methodologies and analytic frameworks to learn more about how students individually and collaboratively engage in argumentation.

6 | IMPLICATIONS

This study examined the ways that sociograms derived from SNA could be used to better understand interactional patterns associated with argumentation discussions. Although this study was exploratory in nature, the findings are promising as they demonstrate the many ways that SNA can shed light on classroom members' engagement in the structural and dialogic components of this science practice. Specifically, this study illustrated how sociograms can capture each component of argumentation individually, such as students' use of reasoning, as well as simultaneously, like the ways students question around reasoning. Such representations could then be used in turn to study and better understand argumentation within one classroom or across different classrooms.

There are many potential applications of SNA for work around scientific argumentation. For instance, while this study highlighted the classroom members' status in the nodes (as either the teacher or a student, depending on the shape of the node), one could also further examine other factors of interest, such as 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 in sociograms could be of interest for researchers who want to examine relationships between these factors and student engagement in argumentation. This is important as studies have shown that teachers can have various expectations about students' abilities to engage in argumentation, depending on students' backgrounds and schooling contexts (e.g., Katsh-Singer, McNeill, Loper, 2016). Also, like Ryu and Lombardi (2015), one could evaluate how students' engagement in argumentation changes over a period of time. For instance, sociograms of argumentation discussions from different time points in the school year might allow for examinations of how classroom discourse practices do (or do not) change toward encompassing argumentation. Alternatively, a single discussion could be examined at time points of particular interest, such as a student bringing in a piece of evidence that resulted in the conversation shifting toward many students getting involved. Then, one could examine changes in who is involved and how over the course of one argumentation discussion.

In terms of practice, one cannot help but wonder about the power of sociograms as tools for helping teachers and students understand their own interactions. Similar to Yoon's (2011) study, sociograms could be used as interventions, though it would be important to tease 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 their questioning and provide students with prompts that guide them in making sense of the visualizations (e.g., Are there any patterns that you see? Who are people generally asking questions to?). Teachers might also learn through such an intervention. For instance, while Mr. McDonald was fairly removed from his students' science seminars, 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 encourage them to step back during the next argumentation discussion. Relatedly, critical examinations of students' argumentation discussions might enable teachers to reflect upon which of their students are involved in the science practice, which students are not, and subsequently how they might better support marginalized voices.

ACKNOWLEDGMENTS

I wish to thank Kate McNeill, Patrick Proctor, Kristen Bottema-Beutel, Lisa Marco-Bujosa, and Rebecca Louick for their invaluable feedback on this manuscript, as well as Erin Bleck for her assistance with data analysis. This study was supported by the project *Constructing and Critiquing Arguments in Middle School Science Classrooms: Supporting Teachers with Multimedia Educative Curriculum Materials*, which was funded by the National Science Foundation (Grant No. DRL-1119584). Furthermore, the writing of this study was supported by a dissertation fellowship from Boston College's Lynch School of Education. Any opinions expressed in this study are my own and do not necessarily represent those of the funding agency, Boston College, or The University of Texas at Austin.

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How to cite this article: González-Howard M. Exploring the utility of social network analysis for visualizing interactions during argumentation discussions. *Science Education*. 2019;1–26. https://doi.org/10.1002/sce.21505