Interactional patterns in argumentation discussions: Teacher and student roles in the construction and refinement of scientific arguments

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Boston College Electronic Thesis or Dissertation, 2017

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Program of
Curriculum and Instruction

INTERACTIONAL PATTERNS IN ARGUMENTATION DISCUSSIONS: TEACHER AND STUDENT ROLES IN THE CONSTRUCTION AND REFINEMENT OF SCIENTIFIC ARGUMENTS

Dissertation by

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Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

May 2017

Abstract

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Teacher and student roles in the construction and refinement of scientific arguments

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Recent science education reform documents and standards, such as the *Next Generation Science Standards* (NGSS), call for school science to better reflect authentic scientific endeavors by highlighting the centrality of students engaging in science practices. This dissertation study focuses specifically on argumentation (through the modality of talk), one of the eight science practices emphasized in the NGSS. Although extensively studied, argumentation rarely occurs in classrooms. The absence of this science practice in classrooms is partly due to the student-driven exchanges required by argumentation differing greatly from the interactions that occur during traditional instruction, where students primarily speak to and through the teacher. To transform the type of talk that occurs in science classrooms it is necessary to examine discourse patterns, as well as the roles classroom members take on, in order to identify and develop strategies that can facilitate the shift in discourse norms.

This dissertation employs a mixed-methods approach, using social network analysis (SNA), multiple case study methodology, and discourse analysis (DA), to deeply examine video recordings of three middle school classrooms engaged in argumentation through a science seminar (a type of whole class debate). Findings from the SNA

highlight the importance of argumentation research integrating a focus on argument structure with dialogic interactions, and point to the benefits of using multiple types of representations to capture engagement in this science practice. Furthermore, examining the manner by which teachers articulated student expectations and goals for the argumentation activity suggest the need to continue supporting teachers in developing and using rich instructional strategies to help students with the dialogic component of argumentation. Additionally, this work sheds light on the importance of how teachers frame the goals for student engagement in this science practice, specifically as being either individual goals or communal goals. Lastly, findings from the DA stress the relationship between discourse patterns and interactional norms, and also suggest the need to expand our perspectives of *who* can prompt for critique during an argumentation activity.

Para mis padres y Colin,
que con su amor y apoyo incondicional
hicieron que ésto fuese posible.

Acknowledgements

First and foremost, I would like to thank my family. Mami y Papi, thank you for instilling in me a love for learning, a strong sense of curiosity about the natural world, and compassion for others. The love and dedication that you both put into your work as educators is inspirational, and what I aspire to demonstrate in my career. Ferni, thank you for being an awesome, loving, and supportive hermanito. You were my first best friend and you always know what Michael Scott quote to say to fit every situation.

I am extremely appreciative for the guidance and support of my dissertation committee, Drs. Kate McNeill, Patrick Proctor and Kristen Bottema-Beutel. Kate, I cannot find the words to adequately thank you for these past years. I am so grateful for all of the opportunities and learning experiences that I have had with you across research, teaching and professional development. You have been a caring mentor and friend, who has shown me how to carry out rigorous and high quality research, always in the service of improving the educational experiences of students and teachers. I am excited for continuing to work with, and learn from you, in the future. Patrick, thank you for helping me critically examine, and think about, the relationship between science and language learning. Kristen, I have enjoyed and learned much from our conversations, and will undoubtedly never think about language use in the same way again.

To the C&I Department, thank you for all of your support and encouragement these past five years, and for making Boston College a community I am proud to have been a part of. To my cohort, I learned so much from each of you and am thankful for your perspectives, advice and conversations. But especially, I would like to acknowledge Becca. Thank you for the numerous hours of “work dates” spent at the various circle tables in Campion, as well as in coffee shops, libraries and at each of our houses. Your friendship throughout this journey helped make what could have otherwise been an isolating experience, very enjoyable and rewarding.

I would also like to thank the various members of the MECM research team throughout these years. Suzy, it has been a pleasure to work with you, and I really hope that our paths cross again in the future. Mandy, Rebecca, and Lisa, thank you for your advice, support, collaboration and friendship these past years – it was wonderful being cubby buddies with you all. Erin Bleck, thank you for your assistance transcribing and coding what at times felt like an endless supply of data.

My greatest thanks goes to my wonderful husband, Colin. Thank you for encouraging me to pursue my doctorate degree; for supporting me throughout the whole process; for always believing in me, particularly when I doubted myself; and for helping me find balance between work and life. Also, thank you for allowing me to turn our dining room table into my “dissertation station” for the past few months. I promise to clean it up soon. I love you today, y te amaré siempre.

Table of Contents

List of Tables and Figures

Tables

Figures

Chapter 1 – Introduction

For the past few decades, science educators and researchers have been concerned with the way that science is presented in school. Traditional characterizations of science education tend to include students passively memorizing discrete facts and ideas, as well as carrying out prefabricated experiments that demonstrate particular concepts (Osborne, 2010; Songer & Linn, 1991). These depictions omit students participating in critique and construction, social elements that are fundamental to science (Ford, 2008). Truly preparing students for both science-related careers and for making informed decisions in this modern innovative world requires learning experiences that exceed regurgitating science facts. In order to remedy this issue, many arguments have been put forth contending that the goals of science education should have a more genuine relationship with the field, and with practical applications of scientific knowledge (Duschl, Schweingruber, & Shouse, 2007).

Knowledge Construction in Science

Developments in science are motivated by humans' desire to make sense of the natural world (NRC, 2012). Guided by this curiosity, evidence is gathered and claims are constructed that explain our current understanding of a particular phenomenon. This is a continuous process; we never reach "truth" because what we know could continue to change as new evidence arises. Specifically, as data are collected through measuring and observing phenomena of interest, alternative explanations are constructed against which initial ideas are compared and evaluated (Ford, 2008). For instance, in the early twentieth century the few scientists who believed that global warming was indeed occurring thought that this process would be purely beneficial to humans:

> By the influence of the increasing carbonic acid in the atmosphere we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind. (Arrhenius, 1908, p. 63)

However, increasing temperatures over the past century have actually resulted in numerous detrimental impacts, including rising sea levels and floods, quicker spreads of diseases, environmental devastation caused by imbalances in ecosystems, and agriculture harmed by unprecedented heat waves and droughts (Weart, 2015). Because of all this contradicting evidence and the debates that ensued, we now know that prior assumptions about the impacts of greenhouse effects were incorrect, and instead, these occurrences indicate that this phenomenon is real and has dire consequences for life on this planet. Scientific history shows how disciplinary progress is fueled by the emergence of new evidence, which in turn causes revised and improved understandings of the natural world (Collins & Pinch, 1993). However, evidence on its own does not bring about changes in scientific knowledge. Scientific progress is driven by the social practices that scientists engage in around evidence.

Scientific work is undertaken in alignment with normative values and criteria that are established by the scientific community (Kuhn, 1962). Research on the practices of scientists (e.g., Latour, 1980; Longino, 1990) have characterized a number of highly interrelated activities as epitomizing how scientists engage in their disciplines. These activities include socially working out problems in real time – which can occur informally through discussions with colleagues, or formally via publications and conferences – as well as engaging in an "iterative process of argumentation, model building, and refinement" (Duschl et al., 2007, p. 9-11). However, the manner by which this work is conducted is not usually revealed to the public, further mystifying the epistemological underpinnings of science (i.e., *how* scientists come to know what they know) (Latour & Woolgar, 1986). Because science permeates and influences many aspects of modern life, understanding science as a practice is important for all members of society so that they can make sense of information they receive about the natural world (NRC, 2012). For instance, many socioscientific issues are present today, such as genetically modifying foods to obtain desired characteristics (e.g., corn that can withstand certain pathogens). Thus, knowing how to cipher through relevant scientific evidence and irrelevant information that is heard or read regarding these topics is a valuable skill for people to have. In order for citizens to develop the abilities needed to engage in debate and make informed decisions about natural phenomena that impact their daily lives (e.g., voting for or against hydraulic fracturing) it is essential that schooling attend to teaching students "the difference between a personal (or political) perspective on a scientific issue and a scientific perspective" (Ford & Forman, 2006, p. 3).

Traditional Science Instruction

Science is taught in school settings in ways that contrast how the discipline is carried out in real life (Osborne, 2010). Science classrooms are dominated by teacher talk (Lemke, 1990) that is motivated by the purpose of transmitting information about the natural and living world to students (Osborne, 2014). Although teachers often encourage students to contribute during class, common discussion styles (i.e., lectures and recitations) include a rigid structure that limits the extent to which students can share differing ideas, respond to their peers' contributions, and actively make sense of natural phenomena (i.e., engage in scientific sensemaking) (Wells & Mejia Arauz, 2006). Class discussions often encompass a discourse pattern in which the teacher initiates talk by asking a question, a student responds to this question, and then the teacher evaluates and/or provides the student with feedback (initiate-response-evaluate, or IRE; Cazden, 1988). The authoritative perspective on teaching that prevails in science classrooms places students as passive recipients of previously determined facts (Scott, Mortimer & Aguilar, 2006), with the teacher as primary knower and hence the sole person capable of legitimizing students' ideas (Cornelius & Herrenkohl, 2004). Grounded in this stance, traditional science education has perpetuated the "mistake stigma" (Herrenkohl, Palincsar, DeWater & Kawasaki, 1999) where only the correct answer is valued during the learning process. All of this is contrary to what actually happens in science. Such a view leaves out the reality of science as a messy, ongoing, social process in which scientists constantly conduct investigations and make observations to gather new data, grapple over contradicting evidence, and engage in critical debates to determine the best explanations for natural phenomena.

In addition, traditional science instruction contradicts what we know about how students learn. Students are not empty vessels into which teachers can pour facts. Instead, students bring to school preconceived ideas about how the world works that they have developed through observations and experiences during their childhood (Michaels, Shouse & Schweingruber, 2008). Although these notions can sometimes be incomplete or incorrect, they are important stepping-stones for their learning. Developing deep conceptual understandings requires that students actively participate in the learning process (Sawyer, 2014), which enables them to confront and overcome misconceptions, or alternative ideas, about science. Specific to science learning, an instructional strategy that has been shown to facilitate conceptual change is “bridging” (Brown, 1992), which entails engaging students in a sequence of situations that helps them bridge from their misconceptions to newly formed scientific understandings as they gather and make sense of scientific evidence. Furthermore, research has demonstrated that students can become more active in their science learning when classrooms are designed to be communities of scientific practice (Rosebery, Warren, & Conant, 1992). Students socially construct scientific knowledge in these types of classrooms through iterative processes and activities that allow them to develop theories, collect and analyze data, engage in argumentation, and subsequently refine theories (Bransford, Brown & Cocking, 1999). Thus, formal learning environments ought to provide students with access and opportunities for engaging in the discursive practices that result in the construction of scientific knowledge (Driver, Newton & Osborne, 2000). Opportunities like these could equip and prepare a citizenry that understands and engages in contemporary debates.

Recent Science Education Reform

Towards this end, United States science education has recently undergone major reform through the creation of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). Embracing and applying research findings (NRC, 2012), these standards were written to better reflect authentic scientific endeavors and what we know about how students learn. Specifically, the NGSS encompass three-dimensions that require students to: (1) connect cross-cutting concepts across various fields in science; all the while (2) engaging in science practices; in order to (3) demonstrate deep understanding of disciplinary core ideas. The view of science proficiency described in these standards highlights the centrality of students engaging in science practices in order to better understand the field's epistemic basis (Duschl & Grandy, 2013). Science practices encompass the "major practices that scientists employ as they investigate and build models and theories about the natural world" (NRC, 2012, p. 2-5), including asking questions and constructing explanations. Having students engage in these practices encourages them to actively participate in the social construction of their knowledge, all the while gaining a rich understanding of the nature of science (Osborne, 2014).

However, successfully implementing the changes outlined in these reform standards will require a large shift in how science has been traditionally taught, impacting both teachers and students (Krajcik, Codere, Dahsah, Bayer & Mun, 2014). Moving away from instruction that relies on presenting information to be learned, NGSS-aligned pedagogy instead requires that teachers support students in constructing their own explanations of science phenomena. As such, the participation frameworks (Goffman, 1981) that tend to govern science classrooms – which encompass the roles and expectations of all classroom members (i.e., teacher and students), as well as the goals that drive tasks – will need to alter in order for students to authentically partake in science practices. Without doing so, tensions may arise, and the educational vision described by the NGSS may not come to fruition.

Argumentation

Among the eight science practices emphasized in the NGSS, this study focuses on argumentation, which plays an essential role in scientific discourse (Bricker & Bell, 2008) and is fundamental to how science knowledge is constructed and refined over time

(Driver, Newton, & Osborne, 2000). Argumentation can occur across language modalities and student configurations, such as writing individual arguments or debating a question within a small group. Specifically, this study will focus on whole class, oral engagement in this science practice. Unlike traditional classroom discussion, argumentation entails a participation framework in which students interact directly with peers as they drive instruction, with the goals of engaging in critique (Henderson, MacPherson, Osborne & Wild, 2015), persuasion and sensemaking (Berland & Reiser, 2011). Similar to Jiménez-Aleixandre and Erduran (2008), I conceptualize this science practice as encompassing both a structural dimension that details how an argument is made up of a claim supported by evidence and reasoning (McNeill, Lizotte, Krajcik & Marx, 2006), and a social dimension that includes the dialogic interactions individuals engage in when constructing, critiquing, and revising arguments (Ford, 2012).

Although argumentation has been extensively studied in science education, it rarely occurs in science classrooms (Osborne, 2010). Making argumentation a key component of classroom instruction is a long and difficult process for both teachers and students (Simon, Erduran & Osborne, 2006). Research findings illustrate some of the challenges classroom communities have encountered engaging in this practice, including appropriately supporting student interactions through questioning (McNeill & Pimentel, 2010), and providing students ample opportunities to learn and engage in argumentation with time constraints due to high-stakes testing (Alozie, Moje & Krajcik, 2010). Because the United States' education system reflects a myriad of student populations and educational settings, it is important to develop understandings of what argumentation engagement might look like in different classrooms. To move from IRE to argumentation

– transforming the type of interactional patterns that dominate discussions in science classrooms – it is necessary to examine conditions that are in place when this practice is being appropriately enacted. Knowing more about the varied circumstances that support argumentation will enable educators to identify and develop instructional strategies that can facilitate and support a shift in discourse norms (Kuhn & Reiser, 2006).

Much research has investigated science instruction that pushes away from teacher-led and mediated classroom talk where the focus of discussion is around content acquisition (e.g., Berland & Reiser, 2009; Pimentel & McNeill, 2013; Driver, Newton, & Osborne, 2000; Alozie, Moje, & Krajcik, 2010). However, as a field we do not yet have a deep understanding of what it looks like for students and teachers to successfully engage in argumentation discourse in science classrooms. This includes knowledge about what interactional patterns of argumentation discussion may look like, roles teachers and students might take on, and the instructional approaches that support this science practice (including how the goals of an argumentation task are framed). In this dissertation, I hope to offer new insight into this area through analyses of three different middle school classrooms that were engaged in an activity called a "science seminar," a type of whole class argumentation discussion. In prior work (McNeill, González-Howard, Katsh-Singer, & Loper, in press; Marco-Bujosa, McNeill, González-Howard, & Loper, 2017), these classrooms were identified as having successfully engaged in this science practice. Thus, they provided a strong context in which to deeply explore students' argumentation across the structural and dialogic components of this science practice. Moreover, it was important to conduct this study in middle school classrooms since this time period has been documented as critical for dissuading or keeping students interested in science

(Britner & Pajares, 2006). In the following section, I provide an overview of this dissertation study, describing the content of each chapter. I also articulate the various sets of research questions that guided this work.

Dissertation Overview

Six chapters follow this introductory chapter. In Chapter 2, I situate this dissertation study in the field of argumentation, and present a review of related literature around dialogue in science classrooms and participation frameworks for this science practice. Chapter 3 includes a description of the curricular context in which this study was embedded, the participants, and the mixed methods approach that I took to analyze video recordings of the three focal classrooms' science seminars. Specifically, this mixed methods approach entailed an examination of the science seminars using social network analysis (SNA), multiple case study methodology, and discourse analysis (DA). For each of these methods, I provide an explanation of the approach and then describe the steps taken to analyze the data. In Chapter 4, I describe the results from conducting the SNA of the science seminars, which included creating sociograms (a type of visual representation) that shed light on the interactional patterns during these argumentation discussions. The results in this chapter were guided by the following research questions:

- How are the structural and dialogic components of argumentation represented in three middle school science classrooms?
- What interactional patterns do sociograms highlight in the argumentation discussions?

Chapter 5 addresses the participation frameworks articulated by two of the focal teachers (Ms. Ransom and Mr. McDonald; both pseudonyms) during the introduction to the science seminar activity. This chapter highlights the similarities and differences between how these teachers framed student expectations for this argumentation task, as well as the goal for the activity. Specifically, this exploration was informed by the following research questions:

- How did Ms. Ransom and Mr. McDonald convey the participation framework that would inform the science seminar activity?
- How does the teachers' framing during the introduction align with students' engagement during the science seminar?

Chapter 6 focuses on a subset of the seminars, particularly on the ones that showed higher frequencies of students critiquing their peers' ideas. This portion of the dissertation was driven by the research questions:

- What are the interactional patterns around critique in the focal groups' science seminars?
- What interactional moves do the teacher and students use to mutually construct an argumentation discussion that engenders critique?

Lastly, in Chapter 7 I draw upon relevant literature to discuss conclusions and implications from this study's findings. I then end with a discussion of the limitations of this work, and describe possibilities for future research.

Chapter 2 – Literature Review

To contextualize this study within the larger field of science education, I review three areas of research. The first area, dialogue in science classrooms, concentrates on the critical role that talk plays in science education, and describes how classroom discourse relates to students' learning experiences and their understandings of the discipline. I then turn to argumentation in science education, where I articulate why argumentation is the focal practice in this study, how it relates to classroom dialogue and the manner by which I am operationalizing this science practice. Finally, I conclude by discussing participation frameworks inherent to engagement in argumentation. This section focuses on how argumentation requires a shift in discursive patterns, which necessitates new rules for classroom talk (especially in terms of teacher and student roles), revised learning goals, as well as the development of instructional strategies to support these changes. This section also reviews methodological approaches that have been used for analyzing argumentation discussions, mentioning advantages and limitations to these analytic techniques. This literature review makes the case for implementing new methods for characterizing when and how students engage in argumentation discussions. In particular, these approaches are necessary to capture the complex dimensions of this social practice. Also, more knowledge is needed around how particular framings and interactional moves by teachers and students can better support classroom engagement in argumentation.

Dialogue in Science Classrooms

Learning Science Through Discussion

Learning experiences are created through a variety of discursive practices (Kelly, 2014), which include the way a teacher frames a task, how students are expected to interact with one another in order to complete the task, and the manner by which ideas are accepted or dismissed during discussion. Because of its role in learning, classroom discourse has become increasingly recognized as a salient research focus in science education (Kelly, 2007). Examining discussions within a science classroom provides insight into how the teacher and students engage in scientific sensemaking, as well as who is – and, who is not – participating in this process. It is essential that students engage in classroom talk in order to develop and refine knowledge, as well as to communicate their thinking to their teacher and peers (Michaels, O'Conner, & Resnick, 2008). Recognizing that a student is not participating in the discussion, or that actions (knowingly or not) are being taken to alienate them from talking, is important for improving learning opportunities.

This perspective has roots in Vygotskian (1934/1986) theory that emphasizes the social nature of learning: the contention that students' interactions with peers, as well as with their teacher, influence their educational experiences. Partaking in classroom discussions provides a venue for students to articulate their thinking, which is important for the learning process as it allows them to compare and contrast older understandings with newer ideas (Mercer & Littleton, 2007). Realizing differences between ways of thinking facilitates the internalization of new information, and dialogue supports students in comparing and contrasting older understandings with newer ideas. Within this view, learning is inseparable from the linguistic interactions that mediate the process. Sociocultural theory further argues that, although they are separate functions, thinking and speaking are closely interrelated and thus an important area of focus in terms of supporting and evaluating learning (Lantolf, 2000). Sawyer (2014) explains how "articulating and learning go hand in hand, in a mutually reinforcing feedback loop" (p. 10). Thus, as students verbalize an idea, even one that is not fully formed nor completely grasped, they begin to develop a deeper understanding of the concept being learned.

Discursive Interactional Patterns

The exchanges that occur between students and their teachers can be used to determine patterns of interactions during classroom talk. Interactional patterns vary as a result of many factors, including who is involved in the discussion (i.e., only students, or students and their teacher) as well as the purpose of the discussion. The most common interactional pattern during whole-class discussions 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 student's answer (Cazden, 1988; Mehan, 1979). This pattern of initiation, response and evaluation (i.e., IRE), with short, often unconnected, exchanges being heavily directed by the teacher, can proceed for the entirety of a whole-class discussion (Crawford, 2005). Mortimer and Scott (1993) describe the communicative approaches taken during classroom discussions as falling on an authoritative-dialogic continuum, where authoritative talk is dominated and steered by the teacher while dialogic talk includes greater student participation and more student-to-student interactions. As such, the IRE interactional pattern that dominates science classrooms is associated with an authoritative approach.

Many critiques have been made of this transmission-focused mode of instruction, one of which includes it not permitting student-to-student interaction. Instead of speaking with their peers, students' contributions go to and through the teacher. Subsequently, the teacher becomes the sole person addressing and validating students' ideas (Lemke, 1990).

This type of classroom talk has also been criticized for being exclusive of multiple perspectives since the teacher steers and bounds the conversation to achieve a desired objective (Scott, Mortimer, & Aguiar, 2006). Having opportunities to hear and critique multiple ideas is critical to students developing a deep understanding of a phenomenon, as “comprehending why ideas are wrong matters as much as understanding why other ideas might be right” (Osborne, 2010, p. 464). Further, the IRE pattern of discussion conflicts with disciplinary ways of collaboratively constructing knowledge (Lemke, 1990). Scientists do not work in isolation; they work together and communicate with colleagues, critiquing and building on one another’s work, in order to jointly develop a stronger understanding of natural phenomena. Moreover, IRE tends to reinforce the idea that only correct answers are valuable (Herrenkohl, Palincsar, DeWater & Kawasaki, 1999). This message is problematic in that it can further the inappropriate view of science learning as memorizing uncontested facts. The focus on dialogue is important for this study because successful argumentation occurs when students engage in dialogic interactions, which is not what they are accustomed to experiencing in science classrooms. Shifting discourse patterns to align with argumentation will thus require intentional moves away from more commonplace authoritative communicative approaches.

Argumentation in Science Education

The Epistemological Role of Argumentation

The practice of scientific argumentation plays an important epistemic role in how knowledge about the natural world, be it through explanations or models, is generated and revised over time (Jiménez-Aleixandre & Erduran, 2008; Bricker & Bell, 2008). The scientific community's manner of carrying out work is subject to values and normative criteria that are collectively accepted (Kuhn, 1962), which includes partaking in practices such as argumentation. The scientific enterprise occurs and progresses as scientists engage in these agreed upon practices. Specifically, as new evidence is collected, it is compared and contrasted to existing data and observations. Although evidence can be used to further substantiate an existing explanation for a natural phenomenon, it can also shed light on the possibility of other explanations. Competing claims naturally give rise to debate, prompting the scientific community to challenge previously accepted ideas. The disciplinary community is expected to hone in on, and critique flaws of, potential knowledge claims until no more flaws can be identified (Ford, 2012). The strongest claim, the one that has best withstood critique, then becomes the current scientific knowledge (which is subject to change as new evidence emerges in the future). Thus, scientific knowledge is advanced through an iterative process of constructing, questioning, evaluating and revising explanations and models of phenomenon; all social interactions encompassed within argumentation (Driver, Newton & Osborne, 2000).

Argumentation in Science Education Reform

In the same ways that scientists develop and revise understandings of natural phenomena, recent efforts contend that students should also have an active role in making sense of nature (Duschl et al., 2007). Recently, a committee of science education experts was charged with developing a research-grounded framework that describes the important features that K-12 science education should include. This work was meant to provide not only a description of content that should be covered, but also suggestions for how these ideas could be developed across grade levels, and what all students should know by the time of high school graduation. The vision for science teaching and learning that this group created was called *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). A big idea underlying this effort was that students should be learning and making sense of nature in ways that mirrors how scientists do so in the real world. As such, the committee recognized that, "students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined" (NRC, 2012, p. 218). Thus, this reform document argued for greater disciplinary authenticity in pedagogical practices, pushing away from traditional science education that has often emphasized the memorization of facts. This NRC report subsequently informed the development of the *Next Generation Science Standards* (NGSS Lead States, 2013). Responding to the NRC's framework, these standards encompass three dimensions: disciplinary core ideas (DCIs), crosscutting concepts, and science and engineering practices. Disciplinary core ideas include core scientific knowledge; crosscutting concepts provide a way to link across the DCIs (e.g., patterns, or cause and effect); and science practices encompass the ways that scientists investigate, construct and revise models and theories about the natural world.

While the explicit call for student engagement in science practices is unprecedented in science standards, its inclusion is also intentional (NRC, 2012). In the past, teachers were encouraged to teach science as a process of inquiry, an approach that has received much criticism. One reason behind the dissatisfaction with the term *inquiry* is that it has been interpreted to mean different types of teaching strategies (Pruitt, 2014), from doing "hands on" activities to reading and discussing expository texts to carrying out investigation. A variety of meanings are problematic because educators might include in their lessons any activity they understand to fulfill this instructional criterion believing that they are engaging their students in authentic inquiry, when in reality they are not. Furthermore, traditional interpretations of inquiry have tended to serve the function of illustrating ideas put forth by the teacher, which contradicts views of inquiry as a means for developing a deeper understanding of how science is actually carried out (Abd-El-Khalick et al., 2004). Similarly, Osborne (2014) has argued that – unlike teaching science as practice – teaching science as inquiry promotes the learning goal of students seeking an understanding of older, previously established knowledge about the natural world. This deepens the tendency for teachers and students to misconstrue science as being "final form" (Duschl, 1990); where there are theories and problems about the natural world that have already been figured out, which the teacher needs to transmit to their students. On the contrary, science as practice encompasses a different meaning of what counts as knowledge, and thus what it means to learn and do science in school. When students engage in science as practice they learn not only science ideas and theories, but also more importantly, how to apply this knowledge to novel situations.

Many have argued that, because argumentation is an essential discourse practice in science, it ought to be promoted in science education (Jiménez-Aleixandre, Rodrígez & Duschl, 2000; Duschl & Osborne, 2002). As such, one of the eight science practices emphasized in the NGSS (2013) is *engaging in argument from evidence*. As articulated in Appendix F of the NGSS, "Whether investigating a phenomenon, testing a design, or constructing a model to provide a mechanism for an explanation, students are expected to use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits” (p. 13). This document further describes how across grades K-12, students’ experiences around this science practice build on one another so that they learn how to construct and defend arguments (in written and oral form) using relevant evidence, provide and receive critiques from peers, and evaluate the merit of currently accepted explanations about the natural world (NGSS, 2013). Additionally, shifting away from traditional means of science instruction, this definition reconceptualizes what counts as knowledge, and encompasses the learning goal of students engaging in knowledge construction.

Defining Argumentation

Researchers in the field of science education have different theoretical perspectives about the role of argumentation in teaching and learning. As a result, various analytical frameworks have been used to conceptualize what argumentation is and how to evaluate a classroom community’s engagement in this practice (Sampson & Clark, 2008). In this work, I view argumentation as not only foundational to students’ knowledge construction about the natural world, but also a learning goal in itself (i.e., the ability to engage in this practice). Consequently, I operationalize this practice as encompassing both structural and dialogic components (Jiménez-Aleixandre & Erduran, 2008; McNeill, González-Howard, Katsh-Singer & Loper, 2016). 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 engaged in the dialogic process of argumentation, structural features of an argument (i.e., claim, evidence, reasoning) are discussed and debated.

In terms of an argument's structure, this practice 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. Data that are used as evidence can be either firsthand, meaning they were collected by the individual analyzing and reporting the data (e.g., results from an experiment that students conduct), or secondhand, which signifies that it was gathered by someone else (e.g., data tables of information about stars that were collected by NASA). Lastly, reasoning is an explanation of how the evidence supports the claim, which often includes scientific principles (McNeill & Krajcik, 2012). For instance, imagine a teacher asks her students to write an argument that answers the question, "What caused the dinosaur extinction?" A student then writes the following: *A chain of volcanic eruptions 65 million years ago caused the dinosaurs to go extinct. Scientists have discovered that sedimentary rock layers all over the world dating from 65 million years ago contain iridium. As volcanoes erupted they would have sent dust and ash containing iridium from those rock layers into the air, which then settled on surrounding rocks. Consequently, the iridium in the sedimentary rock layer suggests that numerous volcanoes erupted 65 million years ago.* In this example, the claim is captured in the first sentence, the evidence in the second, and reasoning in the third and fourth. However, it is not expected (nor developmentally appropriate) that students construct arguments that contain all of these structural aspects at all grade levels. Although young children are capable of constructing claims and supporting claims with evidence, properly integrating science concepts into reasoning is more complex, and tends to be introduced in later grades as students begin to develop a richer understanding of more science content (Zembal-Saul, McNeill & Hershberger, 2013).

However, arguments are not constructed in isolation. As previously described, scientists interact with one another as they engage in the scientific enterprise, advancing what we know and understand about the natural world. Similarly, in order for students to make sense of a topic being learned about, they ought to work in coordination with peers as they construct and revise knowledge claims (Andriessen, 2007). In terms of the dialogic component, this highly interactive practice encompasses critiquing and debating the strength of a particular claim with others, as well as the revision of claims (Ford, 2008; Ford 2012). Furthermore, Berland and Reiser (2009; 2011) contend that argumentation is informed by three interrelated goals – sensemaking, articulating, and persuading – which drive the need for students to develop an understanding of a specific natural phenomenon, explain this understandings to others, and critique peers' ideas while trying to convince others that their own understanding is the strongest. Returning to the previous example about the cause of dinosaur extinction, to engage in the dialogic aspects of this practice a teacher might have students with different claims pair up to debate their arguments:

- *Colin: "I think volcanoes erupting caused the dinosaurs to go extinct because of all the iridium that has been found in sedimentary rock layers."*
- *Julia: "What does iridium have to do with volcanoes erupting?"*
- *Colin: "Iridium is not normally found on Earth's crust, but it is found deep inside of the Earth, and volcanic eruptions would cause it to come to the surface."*

- *Julia: "Oh I see. But what about asteroids? Asteroids also have a lot of iridium, so the iridium that scientists found could have been from an asteroid hitting the Earth."*
- *Colin: "I hadn't thought of that. But is there any proof that an asteroid hit an Earth in the past?"*
- *Julia: "Yeah! Geologists found a huge crater near Mexico that dates to abut 65 million years ago, which they think was created by an asteroid hitting the Earth. That's around the same time that dinosaurs went extinct."*
- *Colin: "Hmmm, so maybe it was an asteroid that killed all the dinosaurs."*

In this instance, both students articulate their claim explaining why the dinosaurs went extinct. Julia questions the evidence in Colin's argument, shedding light on the idea that other factors could have resulted in iridium being found in sedimentary rock layers. By taking this action she is also attempting to persuade him that her argument is strongest. Thus, the complex processes that occur during argumentation include students constructing knowledge claims, questioning and critiquing one another, building on the ideas of their peers, and subsequently revising claims if necessary.

The Role of Argumentation in Learning

Numerous learning benefits have been associated with student engagement in argumentation. For example, as part of a project centered on middle school teachers and students, McNeill and Krajcik (2009) investigated the effects of scaffolds on students' written arguments for natural phenomenon. A post assessment that did not include any supports showed that context-specific writing scaffolds during a unit (as opposed to giving students generic writing scaffolds) – in combination with teacher instructional practices around claim, evidence and reasoning – better equipped students to write stronger arguments. Thus, as students learned to use writing in ways similar to scientists, they also experienced improvements in literacy (Pearson, Moje, & Greenleaf, 2010) and communication skills (Jiménez-Aleixandre & Erduran, 2008).

Another advantage of argumentation is that it can help students develop a more accurate epistemic understanding of science (Duschl & Grandy, 2013). Driver, Newton, and Osborne (2000) contend that engaging in argumentation enables students to develop an appreciation for the basis of scientific knowledge claims, that there are plural interpretations for natural phenomena and that through argumentation competing claims can be evaluated and the best explanation can be decided upon. For example, Ryu and Sandoval (2012) explored how a sustained instructional focus on argumentation in a mixed 4th/5th grade classroom influenced children's understanding of epistemic criteria underlying this science practice. They found that over the course of one academic year students began to appropriate criteria for evaluating arguments, focusing mainly on the evidence as well as the fit between the evidence and the claim being made. This enabled students to focus on the importance and thus persuasive power of evidence in arguments.

Furthermore, other studies have focused on the role of argumentation in supporting students' undersanding of science concepts. For example, Venville and Dawson (2010) implemented a three-lesson intervention in which two 10th grade classes received explicit intruction regarding argumentation skills and then had opportunities to employ these skills with their peers in the context of learning about genetics-based socioscientific issues. Students were given surveys before and after the intervention, and their responses were compared to two other 10th grade classes in the same school who had not received the intervention but were also learning about genetics. Both groups' mean genetics scores increased from the pre to post survey; but the group that had received the argumentation intervention demonstrated significantly greater gains in conceptual understandings of genetics compared to the control group. This suggests that another benefit of engaging in this practice is that it promotes a deeper understanding of science content (Zohar & Nemet, 2002). As these studies illustrate, argumentation has the potential of improving students' literacy, communication skills, epistemological understandings of science, as well as their learning of science content.

However, the mere inclusion of argumentation in classroom instruction does not result in these benefits (Jiménez-Aleixandre & Erduran, 2008). Research suggests that many factors can impact how argumentation is enacted in the classroom. For instance, if teachers lack pedagogical content knowledge with respect to this practice they might focus on superficial aspects of argumentation, such as ensuring that students use the word evidence during discussions without a deep understanding of what counts as evidence in science (McNeill, González-Howard, Katsh-Singer & Loper, in press). Subsequently, this could cause students to miss out on understanding the epistemic role of this practice, resulting in "pseudoargumentation" (Berland & Hammer, 2012). Berland (2011) also found that tension between argumentation goals and underlying classroom goals impacts students' uptake of argumentation. For example, if classroom goals emphasize individual outcomes, then collaboration amongst students (i.e., learning from peers' ideas and questions) might be hindered because students would be focused on only acquiring content knowledge presented by their teacher. Furthermore, some teachers have voiced discomfort in allowing students to construct their own knowledge, fearing the possibility of students being left with an incorrect understanding of the topic at hand (Windschitl, 2002; Zohar, 2008). These factors reveal that many different forces are at play when a classroom community is engaging in argumentation. This complexity is important to keep in mind when understanding how and why students and their teacher enact, and discard, particular elements of argumentation.

Participation Frameworks in Argumentation

Defining Participation Frameworks

Research on classroom dialogue has used the concept of participation frameworks to illustrate how academic tasks are coordinated, given social expectations of classroom behavior for accomplishing these tasks (O'Conner & Michaels, 1993). Thus, a participation framework includes both the interactional rights that are inherent to particular activities– such as the roles individuals are expected to take on – as well as the intended goals of these activities (Goffman, 1981; Goodwin, 1990). In a classroom, participation frameworks are constructed and negotiated by the teacher and students through many things, including talk (O'Conner & Michaels, 1996). For instance, Lemke's (1990) work in science classrooms highlighted how the objective of transmitting information from teacher to students aligns with the IRE interactional pattern that prevails in science classrooms. Lemke illustrated how interactional moves during a discussion can indicate that a participation framework aligned with the IRE structure is being used. Specifically, when a teacher asks a question and then pauses, the pause becomes a nonverbal sign that the teacher is bidding for students' responses and that they should raise their hands to be called on. The student that is called upon then answers the question, directing their response to the teacher. Then, when a teacher replies to a student's response with an evaluative remark (e.g., "yes" or "very good") it becomes clear that the purpose of the exchange is to ensure that students know particular information. In terms of roles, these actions place the teacher in an authoritative role where it is assumed that they already know all of the answers, and students are meant to learn solely from them. Exploring the symmetry or asymmetry between the teacher-student relationship, Tabak (2002) suggested three different participation structures based on the roles teachers take on: the monitor participation structure, the mentor participation structure, and the partner participation structure. The partner participation structure best aligns with the intentions of argumentation, promoting a more symmetrical relationship between students and their teacher, and enabling students to direct the learning and to learn from peers. Furthermore, participation frameworks are not static. Tabak and Baumgartner (2004) demonstrated how students take notice of changing participation structures. Specifically, in the case of a high school biology classroom, these researchers found that indicators such as a shift in the pronouns a teacher used during a discussion cued students into different roles and expectations for how they were to participate. For instance, when the teacher did not use exclusive pronouns and instead employed the same form of talk as his students, it became evident to students that he was placing himself on the same plane of participation as them (i.e., partner participation framework).

Engagement in the discursive practices outlined in the NGSS, including argumentation, will require fundamental changes in the participation frameworks of science classrooms. This focus on participation frameworks is unique compared to much of the previous argumentation research. The literature on argumentation has tended to focus on argument structure (e.g., whether students are articulating their reasoning) or the impacts of a curricular intervention on increasing the occurrence of this science practice in the classroom (Clark, Sampson, Weinberger, & Erkens, 2007). However, fewer prior studies have attempted to examine the actual interactions that take place during argumentation. Participation frameworks offer a means by which to analyze such interactions. As evidenced in the discussion of Lemke's (1990) work, participation frameworks impact interactional patterns during classroom talk. Thus, focusing on this concept will enable a better understanding of both the roles that students and their teachers do and do not take on during the science seminar, as well as why the discussion pattern looks a particular way. For instance, the degree to which students question one another might be impacted by how the need to persuade peers or "win an argument" is conveyed prior to, and throughout the argumentation activity, as well as whether or not students feel they are expected (and allowed) to take on a critiquing role with their peers.

Shifts in Classroom Members' Roles

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, it is vital that the teacher make a concerted effort to cultivate a classroom in which argumentation is practiced, promoting dialogic interactions amongst students (Osborne, Erduran, & Simon, 2004). Developing a classroom culture that supports this type of interaction requires purposeful attention from the teacher, in addition to intentional changes in the roles that both teachers and students take on in the science classroom (Simon, Erduran & Osborne, 2006). Teachers often adopt a myriad of roles, which change to align with particular tasks and learning goals; these can consist of motivator, diagnostician, modeler, innovator, and mentor, just to name a few (Osborne & Freyberg, 1985). However, in traditional science classrooms, students' roles tend to be more passive and focused on them being listeners and receivers of information. Yet, engagement in science practices, including argumentation, will require that students enact some of the roles typically reserved for the teacher, such as experimenter and collaborator (Crawford, 2000).

During whole class discussions, teachers' actions impact how students interact with one another. Although students respond to the verbal and non-verbal cues given by their teacher during discussion, research suggests that teachers may not be cognizant of how they affect, and at times constrain, students' participation (Scott, Mortimer, & Aguiar, 2006). Moreover, studies have shown that even when elicited to do so by curriculum, lessons, or a particular activity, some teachers lack the pedagogical skills necessary to transition traditional discourse into argumentation discourse (Alozie et al., 2010; Driver, Newton, & Osborne, 2000; McNeill et al, in press). Incorporating argumentation into science classrooms will require shifts in classroom discourse patterns, especially since many teachers are currently less familiar with these instructional approaches (Windschitl, Thompson, & Braaten, 2011). As such, it is important that we begin to develop a stronger understanding of what these discourse patterns might look like and the roles teachers and students play in those discourse patterns in order to better support teachers and students in making and sustaining these changes.

Pedagogical Supports For Argumentation Discussions

Studies of argumentation have explored facets of the learning environment that may support student engagement in this practice, including whether students are working towards the same goals, and the extent to which these goals align with the purpose of argumentation. Much of this work has been grounded in the concept of "framing" (Goffman, 1974) that attends to individuals' understandings and expectations around a particular task. In terms of schooling, how a student perceives a task to be framed (which is impacted by many factors, such as the teacher's directions and body language) influences how they engage in it. For example, Berland and Hammer (2012) examined various conversational segments from a 6th grade classroom to understand how classroom communities framed argumentation tasks. They found that argumentation occurred when the teacher and students framed the task as involving the need for students to reach consensus (by persuading one another), while also supporting their ideas with evidence. Specifically, at the start of the activity the teacher explained, "What we have to do is come to consensus," (p. 78) and followed this direction by briefly talking about how in science ideas are substantiated with evidence. Then, during the discussion, the teacher stood at the back of the classroom, and provided the speaking student with a yardstick. These moves enabled the task to be framed such that students understood that they should speak with one another (and not the teacher) as they worked towards agreement regarding the lesson's guiding question, and use the yardstick to reference the graph at the front of the classroom as evidence in support of their arguments.

In a similar vein, Berland and Lee (2012) explored the idea that the success of an argument task might be based more on how the task's goal is interpreted by individuals rather than individuals' abilities to engage in the task. Small groups of 5th and 6th graders were video recorded partaking in an activity in which they were meant to come to an agreement about an idea. During the argumentation task, peer legitimization of ideas (especially those that were incorrect) emerged as important in order for all students' ideas to be heard and valued by the group. This process moderated the confrontational aspects encompassed within this science practice because students viewed changing their ideas as acceptable and a safe move to make. This work suggests that a critical factor influencing how students engage in argumentation is not only how a task is framed, but also how students interpret the framing of a task.

Another approach has been to explore how teachers' questioning strategies might support shifts in students' roles and increasing participation during classroom discussions. For instance, McNeill & Pimentel (2009) examined whole class argumentation discussions in three high school classrooms. They found that students more meaningfully engaged with one another's ideas and created more thorough arguments in the classroom in which the teacher asked open-ended questions; this suggests that these types of questions might support particular aspects of argumentation. In a different study, Chin and Osborne (2010) investigated how scaffolding student questioning could be both an epistemic probe (prompting them to consider how they know what they know) as well as a heuristic tool (eliciting reasoning). Students worked in small groups to develop Question Webs, which they then used in combination with other question prompts during a small group argumentation discussion. Researchers characterized successful argumentation as including exploratory talk where students asked a variety of question types, and referenced the structure of an argument in questions (i.e., claim, reasons, evidence). These studies highlight how purposefully integrating questions into argumentation tasks can improve students' engagement in this practice, particularly in terms of desired learning goals (e.g., getting students to interact with peers, or justifying claims with evidence). Taken together, the approaches of framing and questioning shed light on the importance of attending to instructional strategies that may support or hinder changes in participation frameworks. Thus, in my study I am interested in not only analyzing participation frameworks during whole class argumentation discussions, but also of exploring the interactional moves that may impact those frameworks.

Methodological Approaches to Analyzing Argumentation

The methods that researchers have undertaken 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). In this subsection, I mention some approaches that researchers have taken to understand students' argumentation. Sampson and Clark (2008) categorized and described prior methodological approaches under three different issues commonly studied: 1) the structural components of an argument, 2) the content of an argument, and 3) 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, Maloney and Simon (2006) constructed "Discussion Maps" of students' arguments to study student participation during argumentation discussions. 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, and allowed them to examine how students' participation varied across activities. 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 popular approach to examining students' arguments has been through adaptations of Toulmin's (1958) argument pattern (TAP) (e.g., Jiménez-Aleixandre et al., 2000; Zohar & Nemet, 2002). The TAP method primarily focuses on how students organize the structural features of an argument, particularly in terms of the following components: claim, warrants, qualifiers, backings, and rebuttals. For example, Erduran and colleagues (2004) applied the TAP scheme to small group and whole class discussions in middle school science classrooms. They found that this approach was useful in exploring changes in the quality of students' argumentation discourse over an extended period of time, especially in relation to their teacher's varied instructional practices. Yet, depending on the length of students' arguments, issues have arisen with respect to coding the different components encompassed within TAP (e.g., is the student making a claim, or is the statement being used as a warrant?) (Kelly, Druker, & Chen, 1998). Additionally, given how laborious the TAP methodology is to carry out, it is difficult to adapt for large-scale studies (Erduran, 2008).

A 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). In a case study exploring 7th grade students' decision making during debates of socioscientific arguments, Yoon (2008) investigated the manner by which students acquire and evaluate sources of information. This study employed SNA when evaluating students' like-mindedness rankings to determine in-degree scores. In-degree scores are a measure of the total number of connections that are directed toward an individual (Scott, 1991), which, if the relation is directional, can be used to represent an actor's prestige or status in a system (Wasserman & Faust, 1994). In the case of Yoon's study, the in-degree scores were used to determine the status of students and their ideas throughout the course of the study as they engaged in the different argumentation activities. Yoon found that both social and conceptual processes operated in the classroom, such as doing "as the smart kids do", influencing the ideas that students dismissed, as well as those they were willing to take on and make sense of during argumentation discussions. However, this study did not look at whole class engagement in argumentation. Instead, it explored students' decision making based on conversations that they had with one other student (i.e., in pairs).

In a different study, contextualized within four 7th grade classrooms Yoon (2011) explored the visualization affordances of SNA, using social network graphs (i.e., sociograms) illustrating patterns of students' interactions as an intervention for improving group-level processes and learning outcomes. Handheld electronic devices were used to archive participants' interactions, creating a visual graph 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 social network graphs 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. Although Yoon's work provides important insights into the students' interactions, it does not consider the structural and dialogic components of argumentation. The sociograms that students analyzed in the study represented general interaction between individuals in the sense of who talked to whom. These sociograms did not illustrate the nuances of an argumentation discussion (e.g., who asked questions, and to whom; who built on their peers' ideas; who referenced evidence in their contributions, etc.), which is an area that this dissertation study addresses.

Most recently, Ryu and Lombardi (2015) wrote an article discussing the advantages of using mixed methods approaches for analyzing students' classroom talk. These researchers advocate that applying multiple analytic techniques (in their case SNA and critical discourse analysis), allows for a richer understanding of what interactional patterns occur while students engage in talk with peers, and insight into why and how engagement might be occurring. Exemplifying the utility of mixed methods, Ryu and Lombardi present an analysis from a mixed 3rd and 4th grade classroom, in which an experienced science teacher intentionally attempted to encourage less engaged students to participate during conversations by assigning and rotating different roles and responsibilities. Specifically, these roles included the "starter" (the student responsible for explaining the plans and goal of an activity to their peers), the "recorder (the individual that took note of data and was responsible for presenting it to the class), and the “gatherer” (who collected and prepared materials that student groups used to conduct experiments) (Ryu, 2011). Employing both techniques allowed researchers to illustrate how and why over time students’ collective engagement increased. For instance, one English-language learning 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. Moreover, employing critical discourse analysis allowed the researchers to examine and describe the implications of status and power dynamics at play during students’ argumentation. 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.

The recent body of work using SNA in argumentation suggests that this technique is useful because it allows insight into interactional patterns that occur while students engage in this science practice. This is in contrast to previous research in argumentation that has not focused on the dialogic interactions of this practice. The studies reviewed illustrate the various ways that this analytic approach can be employed to provide information about interaction, including the creation of sociograms (visualizations of interactions) or in-degree scores (status ratings in network). Furthermore, as the Ryu and Lombardi (2015) piece illustrated, this approach is also helpful in showing changes in students’ interactions over a period of time. However, research using SNA has not examined teacher and students’ argumentation across argument structure and dialogic interactions, which is a focal area of this dissertation study.

Summary

Recent reform efforts in science education have argued for a new conceptualization of science proficiency, which includes adeptness in science practices (NRC, 2012). One of the eight practices emphasized in the NGSS (2013) is argumentation, which although greatly studied by science education researchers, is rarely seen carried out in schools (Osborne, 2010). Research on argumentation has tended to focus on argument structure (Clark et al., 2007) instead of on the interactions that take place as students participate in this science practice (Ford, 2008). Moving away from interactional patterns that highlight the teacher's role as authoritative – being the sole individual capable of critiquing and validating knowledge (Lemke, 1990; Mortimer &Scott, 1993) – argumentation discussions require that students take the reins of their learning and dialogically interact with peers as they construct understandings of science phenomena (Ford, 2012). Thus, argumentation requires a shift in the discursive patterns that prevail in science classrooms.

The discursive patterns that occur in schools are informed by the expectations of an activity, as well as the roles classroom members are permitted to take on to accomplish the desired task (Goffman, 1981). As such, it is necessary to look into the participation frameworks that support argumentation. Although different from previous argumentation research, this focus on participation frameworks offers a means by which to make sense of the interactional patterns that take place as a classroom community engages in this science practice. Further, analytic issues encountered in prior research suggest that new methods are needed for analyzing argumentation discussions, ways that capture the complex nature of this science practice (across both structure and process).

This dissertation study is at the intersection of these areas. Applying multiple analytic techniques allows for a visualization of the interactional patterns that occur while students engage in argumentation, as well as insight into how and why this might be occurring. Such an understanding could inform instructional strategies and the design of learning environments that promote student engagement in the dialogic aspects of this science practice, such as critique.

Chapter 3 – Methodology

This chapter describes the methodologies I employed to explore various aspects of argumentation discussions, including: the nature of the interaction patterns during this type of discussion; the ways particular teachers articulated the participation framework (i.e., student expectations and the activity's purpose) for the science seminar; and the interactional moves carried out by classroom members during the seminar that encouraged students to engage in critique. This work was guided by three sets of research questions (see Table 3.1 below), each of whose findings are presented in separate result chapters (i.e., Chapters 4, 5 and 6).

Table 3.1: Sets of research questions

Question Set	Research Questions
#1	• How are the structural and dialogic components of argumentation represented in three middle school science classrooms? • What interactional patterns do sociograms highlight in the argumentation discussions?
#2	• How did Ms. Ransom and Mr. McDonald convey the participation framework that would inform the science seminar activity? • How does the teachers' framing during the introduction align with students' engagement during the science seminar?
#3	• What are the interactional patterns around critique in the focal groups' science seminars? • What interactional moves do the teacher and students use to mutually construct an argumentation discussion that engenders critique?

These questions were investigated through an exploratory sequential design (Creswell Clark, Gutmann, & Hanson, 2003). This is a multiple-phase mixed methods design that allows results from the first phase of analysis to be examined in more detail in subsequent phases of analyses (Creswell & Plano Clark, 2007). In the case of this dissertation, the three classrooms' argumentation discussions were first analyzed using social network analysis (SNA), and then multiple case study methodology, and discourse analysis (DA). Each of these methodologies aligned with one set of research questions. However, before delving deeper into these analytic techniques, I will first provide background information on the curricular and instructional contexts in which this study was embedded.

Curricular Context

The data collection for this study took place in the context of teachers piloting two science curricula units that included a specific focus on argumentation. The Learning Design Group at the Lawrence Hall of Science developed the curriculum (Regents of the University of California, 2012; 2013), using a multimodal approach that integrates science and literacy to engage students in science concepts (Pearson, Moje & Greenleaf, 2010). The curriculum prompted students to construct, critique and refine arguments through reading, writing and talking. Further, these argumentation experiences took place across various student configurations (e.g., individual, pairs, small groups, whole class). For instance, students individually wrote arguments; worked in pairs to distinguish cards as either relevant evidence or irrelevant information in support of a claim; collected data in groups of four to determine which of two claims was best justified by evidence; and read and critiqued elements of a written argument as a whole class.

During the 2011-2012 school year, an earth science unit was piloted titled *Plate Tectonics*, which concentrated on how features and events on Earth's surface are caused by the movement of plate tectonics. The unit also emphasized that Earth's surface has changed, and will continue to do so, as a result of interacting plate tectonics. During the 2013-2014 school year, a life science unit was piloted called *Metabolism*. 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. Across both units, teachers' instructional materials were delivered digitally (via an iPad or website), and students received notebooks that contained all of the handouts they would need for the unit. Furthermore, the *Metabolism* unit incorporated virtual simulations into many of the lessons for students to manipulate, which were delivered digitally on a tablet computer.

Each of the piloted units concluded with a science seminar: a whole class activity in which students orally debate explanations to a question using evidence analyzed in previous lessons. During science seminars, students are split into two groups (this is done primarily for management reasons), and the classroom is set up into two concentric semi-circles. Students sitting in the inner semi-circle debate the question, while those in the outer semi-circle listen actively and complete an observation sheet. Halfway through the class time, the two groups switch. During the entirety of the seminar, students are responsible for driving the conversation, listening, critiquing and responding to one another as they debate the question of interest. By interacting with peers about the details and strength of evidence, students engage in an authentic disciplinary practice, all the while developing a more nuanced understanding of different explanatory claims for a particular phenomenon. Throughout a science seminar, the teacher is expected to physically step back and watch from the side, listen silently, and interject only when necessary. In terms of argumentation, this activity encompasses both the dialogic and structural components of this science practice: students engage in the dialogic process of argumentation (e.g., questioning one another and critiquing peers' ideas) while they construct and refine the structure of an argument (e.g., explaining the connection between a claim being made and its supporting evidence).

Though there were similarities between the two units' science seminars, there were also distinct differences (see Table 3.2 for details). For both units, the curriculum provided students with opportunities to gather evidence in support of multiple claims in response to each seminar's guiding question. Depending on the piloted unit, students gathered evidence by analyzing maps or charts. Because each debate topic offered numerous potential claims, students had a need for interacting with one another in order to determine which claim best explained the phenomenon of interest.

Specifically, in the *Metabolism* science seminar, students engaged in an argumentation discussion around the question: When a person trains to become an athlete, how does her body change to become better at releasing energy? Throughout this 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. One study showed how the bodies of identical twins are different if one twin does more athletic training than the other, concentrating on results from a lung test and a mitochondria test. The second study presented results from a heart test and mitochondria test, showing how increased athletic training changes non-athletes' bodies over time. Comparing the bodies of athletes and non-athletes, the third study included results from a lung test and a heart test (see Appendix A for data tables). Analyzing these data enabled student to construct many claims, such as when training to become an athlete, a person's body changes by increased: lung capacity, number of mitochondria, and amount of blood pumped by the heart. Ideally, by the end of this activity, students understand that all of these changes occur in a person's body as they train to become an athlete.

Table 3.2: Information about the science seminars

Unit	Science Seminar's Guiding Question	Possible Claim(s)	Possible Sources of Evidence
Metabolism	When a person trains to become an athlete, how does her body change to become better at releasing energy? [1]	When training to become an athlete, a person's body changes by… • Being able to move more air volume in and out of lungs, resulting more oxygen getting to the cells • Pumping more blood through the heart, which allows more blood (that contains oxygen and glucose) to reach the cells • Increasing mitochondria, which take oxygen and sugar to make energy **Claims are ultimately <u>synergistic</u>*	Data tables of results from three different studies that compared information of athletes and non-athletes (e.g., amount of blood the heart pumps in one minute)
Plate Tectonics	How will the Indian Plate be different in 50 million years?	In 50 million years the Indian Plate will… • Move in a Northeastern direction • Move in a Northern direction • Expand and become larger • Become smaller • Move in a Northeastern direction and expand **Claims are ultimately <u>competing</u>*	Map of the Indian Plate with information about its surrounding plate boundaries including: collision, spreading or subduction zones, nearby active volcanoes, and arrows indicating the direction plates are moving

[1]The question debated during the science seminar has a known answer

Meanwhile, in the *Plate Tectonics* unit the question debated was: How will the Indian Plate be different in 50 million years? Unlike the other science seminar, this activity was anchored in a question that has no known answer. During this unit, students had come to understand how the Earth's surface is made up of plates that are constantly in motion, and that there are numerous types of movements at the boundaries between plates (i.e., divergent, convergent, and transform). Furthermore, students had learned that plate movements result in changes on the Earth's surface, like the formation of volcanoes and deep ocean trenches. In preparation for the science seminar, all 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 (see Appendix B for map). The open-ended phrasing of the question, along with the information students had access to via the map, allowed for many different claims to be made. Some of these claims could have been that in 50 million years the Indian Plate will: move in a Northeastern direction; move in a Northern direction; become larger; or become smaller. Students proposed claims could have also been a combination of these ideas (e.g., In 50 millions years the Indian Plate will move in a Northern direction and become smaller). In comparison with the science seminar from the *Metabolism* unit, which had synergistic claims that would ultimately be combined to form the strongest explanation, during the *Plate Tectonics* science seminar students debated competing claims.

Another difference between the science seminars concerns the observation sheets that the students in the outside circle were responsible for completing. The observation sheet for the *Plate Tectonics* unit asked students to keep tally of when they heard their peers building on one another's ideas, disagreeing politely, offering new evidence, and listening respectfully. It also included an open ended question – Describe one moment in which you saw a student participating especially well – and space for students to rate the discussion on a scale of 1 (poor) to 5 (excellent). The observation sheet for the *Metabolism* unit's science seminar was less structured, and comprised of a single prompt for students to consider while they watched their peers – As you listen to your fellow athletic consultants during the science seminar, write at least one new and convincing idea that you heard – followed by space for students to write notes.

Participants

For this dissertation study, participants were selected from a pool of 15 teachers that were part of a larger project (McNeill, González-Howard, Katsh-Singer, & Loper, in press; McNeill, Marco-Bujosa, González-Howard & Loper, 2016), all of whom piloted one of three curricular units with a focus on argumentation (which includes the *Metabolism* and *Plate Tectonics* units that were described in the previous section). Specifically, 5 teachers piloted each unit. Earlier research from the project suggested that implementing argumentation discussion into classroom instruction was challenging for many teachers (McNeill et al., in press; McNeill et al., 2016). For the purposes of this dissertation, I initially wanted to select the one teacher from each of the three piloted units whose class had received the highest argumentation rating for the science seminar lesson. I will explain how these science seminars were previously analyzed shortly. However, due to technical difficulties around footage from one of the units (i.e., the video footage focused solely on the teacher and/or many students' contributions were inaudible), I chose three teachers' classrooms whose science seminar lessons had been identified as being of higher quality from the two previous described units, and whose video footage allowed me to carry out the desired analyses. Purposive sampling (Patton, 1990) for classroom selection (i.e., selecting participants based on particular characteristics, and the study's objective) was an appropriate method to employ because a goal of this dissertation was to develop a deeper understanding of what it looks like for teachers and students to productively engage in argumentation dialogue, and to illustrate the various ways that this science practice can be successfully enacted.

In the larger project, all of the teachers' science seminar lessons were video recorded and analyzed according to teacher instruction and support of argumentation, as well as student engagement in this practice. The coding schemes used for this analysis were developed using a theoretical framework around scientific argumentation as well as an iterative analysis of the data (Miles & Huberman, 1994). Focusing on key characteristics of argumentation, teacher instruction and student engagement for both the structural and dialogic aspects of this science practice were coded in terms of both presence and quality (i.e., High Quality, Low Quality, Absent). Specifically, the coding scheme emphasized key characteristics of this practice as identified in recent literature (see coding scheme in McNeill, González-Howard, Katsh-Singer, & Loper, 2016). In terms of argument structure, these characteristics include the use of high-quality evidence to justify claims, and explaining the link between evidence and a claim (i.e., reasoning). For the dialogic aspects of this science practice, these features encompass building on and questioning other's ideas, and critiquing competing claims. For example, the subcategory of student engagement in argumentation for the structural feature of evidence would have received a code of "High Quality" if the *majority* of students were heard justifying their claims using scientific data. On the other hand, the same subcategory would have received a code of "Low Quality" if *some* students' contributions included evidence, and "Absent" if *no* students justified their claims with data.

The three teachers that I selected for this dissertation study were assigned pseudonyms: Ms. Ransom, Mr. McDonald and Ms. Allen. In all of these teachers' classrooms, students were frequently observed interacting with one another during the science seminar lesson. Because the initial analyses from the larger project were done on a larger grain size – providing a sense of overall argumentation engagement – it lacked a more detailed explanation of how individuals participated in the seminar, and of variations in the ways that different classrooms carried out the activity. Specifically, it did not account for the patterns of interaction during the discussion, which the SNA focuses on. Furthermore, the initial coding did not provide insight into how the participation frameworks (i.e., classroom members' expectations, as well as the science seminar's purpose) were articulated, nor of how particular aspects of argumentation (e.g., student critique) were engendered, a focus of the DA.

Table 3.3: Teacher backgrounds

Teacher	**Type of Teaching Credential**	**Highest Level of Education**	**Years of Teaching Experience**	**Classes Taught**
Ms. Ransom	Middle school or secondary science	MA	20 or more	Science
Mr. McDonald	Middle school or secondary science	MA	6-10	Science
Ms. Allen	Multi-subject (elementary)	BA	1	All Subjects

Additionally, the focal teachers had various backgrounds, ranging from a first year teacher to one with over 20 years of experience. While two of the teachers, Ms. Ransom and Mr. McDonald, taught science to numerous classes throughout the school day, the third teacher, Ms. Allen, taught one class of students across every subject area (i.e., math, writing, science, and social studies). Further, as illustrated in Table 3.3, these teachers had a range of teaching credentials and educational experiences.

As seen in Table 3.4, the focal teachers also taught in a variety of school contexts. While all of the schools were public, there is clear variation in terms of student demographics of the schools. Compared to Ms. Ransom and Mr. McDonald (who taught in the same middle school), Ms. Allen's school had larger percentages of non-White students, English-learning students, and students receiving free and reduced-price lunch (FRPL), which could be used as a marker for socioeconomic status (SES).

Table 3.4: School and classroom context

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

The National Center for Education Statistics defines a school as having high rates of students in poverty (i.e., from low SES backgrounds) when more than 75% of students enrolled are eligible for FRPL (Aud, et al., 2011). Similar to Katsh-Singer and colleagues (2016), I conceptualized schools with 25-75% of students eligible for FRPL as mid SES schools, and schools with fewer than 25% of students eligible for FRPL as high SES schools. Thus, the three focal classrooms were in high and mid SES schools. These differing classroom contexts provided an opportunity in which to explore images of successful engagement in argumentation with various student populations.

Data Source

This study examined 6 science seminar video recordings, 2 from each teacher's classroom. The focal teachers' classes were split into two groups during the lesson, each of which had an opportunity to engage in the activity. Because a different set of students participated in a given science seminar, I considered each group's seminar to be distinct and address them as such (e.g., Ms. Ransom's Group 1 and Ms. Ransom's Group 2). These science seminars ranged in length, with the shortest lasting a little over 9 minutes, and the longest nearly 18 minutes. The 6 discussions were transcribed, and the seating arrangement during each science seminar, for both the teacher and students, was recorded (see example in Figure 3.1, which is from Group 1 in Mr. McDonald's class).

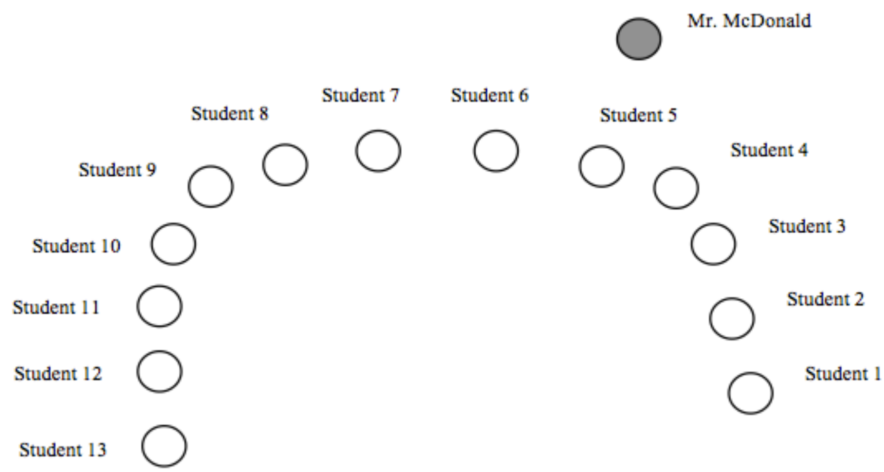


Figure 3.1: Example seating arrangement from Mr. McDonald's Group 1

Recording the seating arrangements was needed to keep track of who was speaking to whom. If any seating changes occurred (e.g., a student left to use the restroom, or a student arrived late to class and joined the activity), the revised configuration was noted. I also included in the transcripts information about whether an individual pointed to or referenced something – such as a chart or map – 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 map as evidence, or the teacher taps on a student's shoulder to encourage them to participate) were important for understanding how the argumentation discussions unfolded.

Analytic Approach

A Mixed Methods Design

The analytic approach I took to carry out this dissertation study encompassed an exploratory sequential design (Creswell, Clark, Gutmann, & Hanson, 2003), which is well suited for deeply exploring complex phenomena (Creswell, 1999). Specifically, this dissertation involved analyzing transcriptions of the science seminar enactments through social network analysis (SNA), multiple case study methodology, and discourse analysis (DA). 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 environment can be construed as a social network in which the teacher and students are actors (Borgatti & Ofem, 2010). The first set of research questions was answered using this methodology. Findings from the SNA prompted additional questions, which were then further explored using multiple case study methodology, and DA. Specifically, due to variation in the interactional patterns across the different classrooms multiple case study methodology (Stake, 2000) was used to examine how Ms. Ransom and Mr. McDonald articulated the participation framework (Goffman, 1981) for the science seminar to their students. This analysis corresponds to the second set of research questions. Additionally, higher frequencies of student critique in particular seminars led to me using DA – a method for studying language in use; Potter & Wetherell, 1987 – to explore the interactional moves carried out by the teachers and students that engendered instances of critique. This work was guided by the third set of research questions. Table 3.5 illustrates how these various methodologies aligned to the different set of research questions, and specifies which seminars where analyzed for each area of this dissertation study.

Table 3.5: Alignment between sets of research questions and methodologies

Question Set	Research Questions	Methodology	Science Seminars Analyzed
#1	• How are the structural and dialogic components of argumentation represented in three middle school science classrooms? • What interactional patterns do sociograms highlight in the argumentation discussions?	Social Network Analysis	• Ms. Ransom's Groups 1 and 2 • Mr. McDonald's Groups 1 and 2 • Ms. Allen's Groups 1 and 2
#2	• How did Ms. Ransom and Mr. McDonald convey the participation framework that would inform the science seminar activity? • How does the teachers' framing during the introduction align with students' engagement during the science seminar?	Multiple Case Study Methodology	• Ms. Ransom's Groups 1 and 2 • Mr. McDonald's Groups 1 and 2
#3	• What are the interactional patterns around critique in the focal groups' science seminars? • What interactional moves do the teacher and students use to mutually construct an argumentation discussion that engenders critique?	Discourse Analysis	• Ms. Ransom's Group 2 • Ms. Allen's Groups 1 and 2

In combining results from different analytic approaches one can benefit from the strengths of different methodologies (Creswell & Clark, 2007; Tashakkori & Teddlie, 1998). Because social phenomena are intrinsically multifaceted, different kinds of methods are needed to best comprehend the layers of complexities (Green & Caracelli, 1997). In the following subsections I review the different methods that I used, explain how they were employed in this study, and discuss how, for the second and third sets of research questions, I used the various techniques (e.g., DA and findings from the SNA) to compliment the analyses of the other.

Social Network Analysis

About this analytic approach. SNA strives to explain the connections, or relationships, between social units in a network (Carolan, 2014). The social units being examined can be made up of individuals, groups, or organizations. In this dissertation study, the social units of interest were individuals, specifically students and their teacher, within a classroom community. A broad range of disciplines (such as sociology, mathematics, and anthropology) have approached analyzing social entities through the perspective of networks (Katz, Lazer, Arrow, & Contractor, 2004). In terms of education, this method has been used to investigate numerous issues including student participation in online learning environments (Thorpe, McCormick, Kubiak & Carmichael, 2007; de Laat, Lally, Lipponen, & Simons, 2007; Lipponen, Rahikainen, Lallimo & Hakkarainen, 2003), changes in teacher communities following professional development (Penuel, Riel, Krause & Frank, 2012; Baker-Doyle & Yoon, 2011), students' decision making during classroom debates (Yoon, 2008; Yoon, 2011), and racial integration patterns of students in multicultural classrooms (Rodkin, Wilson & Ahn, 2007).

Several concepts are fundamental to a discussion of SNA, including actors, ties, 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, many 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 et al., 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 dissertation study, the interactions examined were those that occurred as the three focal classrooms engaged in an argumentation discussion. Specifically, I operationalized and examined "argumentation ties" between classroom members as they participated in the science seminar. One of the outcomes of running SNA is the creation of sociograms, which are visual representations of the ties between actors in a network (Katz et al., 2004). The structure of these sociograms is often of interest to researchers, as they represent an interpretation of the relationship between actors through the nature of the links among them that is being examined.

Conducting the social network analysis. SNA was used to answer the first set of research questions (see Table 3.1). Many steps were taken after transcribing the science seminars in order to conduct the SNA. These steps included: breaking the transcriptions into utterances; coding each of the utterances across argument structure, dialogic interactions, and ties; making valued directed matrices, and then carrying out the SNA, which was used to create sociograms. In the following subsections, I describe each of these steps in further detail.

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 transcript of each science seminar was broken up into utterances. An "utterance" was operationalized as an idea or contribution to the discussion that ideally 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 components (e.g., a student asked 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 3.7 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 93.7% inter-rater reliability.

Coding the utterances across argument structure and dialogic interactions. Along with an undergraduate research assistant, I 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 I later examined. These coding schemes were developed from both the theoretical framework around scientific argumentation outlined in Chapter 2, and an iterative analysis of the science seminar transcripts (Miles & Huberman, 1994). Tables 3.5 and 3.6 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. I also used these coded utterances to calculate percentages of structural and dialogic argument features (e.g., % of student contributions that included evidence, or % of contributions in which students built on other's ideas) that served as an additional analysis through which to look for patterns across and within the different science seminar discussions.

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). Table 3.6 below presents the codes I used for argument structure, a description of each code, and an example utterance that would get marked for each code.

Table 3.6: Synthesized coding scheme for argument structure

Code	Description	Example[1]
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	"During the simulation test that I ran of the athletic and non-athletic twins, 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."

[1]Examples are embedded in the context of the *Metabolism* science seminar

These examples were from the context of the *Metabolism* science seminar. Because the teachers' science seminars were contextualized within different units (i.e., *Metabolism* and *Plate Tectonics*), in order to analyze the various transcripts I needed to incorporate different examples for each code that were specific to a particular science seminar. For example, while data from studies about the human bodies' responses to exercise counted as evidence for the *Metabolism* science seminar, in the *Plate Tectonics* science seminar students might instead have used arrows on a map of the Earth showing plate movement to support claims. Please see Appendix C for the full version of the *Metabolism* unit's coding schemes, and Appendix D for the full version of the coding schemes used for the *Plate Tectonics'* science seminar.

Furthermore, it is important to note that in terms of an argument's structure, I was only interested in claims, evidence and reasoning related to the science seminar's guiding question. I did not code for other arguments 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. Two raters independently coded 20% of each science seminar transcript for argument structure and obtained 96.3% inter-rater reliability.

In addition to the structural elements of an argument that students used during the science seminar, I was also interested in the dialogic interactions between the classroom members as they engaged in the debate (see Table 3.7). The coding scheme for the dialogic interactions was informed by the work of Ford (2008; 2012) and Jiménez-Aleixandre and Erduran (2008). In terms of dialogic argumentation, I was also 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.

Table 3.7: Synthesized coding scheme for dialogic interactions

Code	Description	Example[1]
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	"I wasn't able to complete the simulation test of the athletic and non-athletic twins."

[1]Examples are embedded in the context of the *Metabolism* science seminar

As such, each utterance was classified under one of four possible dialogic argumentation codes. Two raters independently coded 20% of each science seminar transcript in terms of dialogic interactions, obtaining a 93.5% inter-rater reliability. Any coding disagreements that arose were resolved through discussion. Table 3.8 includes a sample transcript that was analyzed using both the structural and dialogic coding schemes. This sample transcript is from Ms. Ransom's Group 1 *Metabolism* science seminar.

Coding the ties. 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). The last column in Table 3.8 notes the ties between classroom members. 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.* This occurs in Turn 12 when Student 3 responds to Student 5's critique about one of the studies. However, we did not automatically consider a response to be directed toward the person who previously spoke, as there were circumstances where this was not be the case. For example, a student might question a statement that was made much earlier in the conversation, or the teacher can call on a student to speak who is not participating in the science seminar.
2. *Examining the content of a response.* For instance, in Turn 17 the content of Student 3's response captures them describing how doing a sport relates to weekly hours of athletic training, commenting on Student 5's idea from Turn 16.
3. *Through gestures seen in the video recordings.* This is why notes were also made of individuals' gestures during the seminar, such as whether they pointed to a

chart in their hands, or stood up and faced one particular person while they talked. Furthermore, it is not uncommon for a speaker to respond to multiple participants within the context of a single turn. In these cases, the turn was separately marked for each particular participant to whom the speaker responded (see Turn 16 in Table 3.8). It is important to note that this definition of recipient is specific to the SNA; this term was conceptualized differently when conducting the discourse analysis. Again, two raters independently coded 20% of each science seminar transcript in terms of ties and achieved 89.7% inter-rater reliability. The few disagreements that came up when coding for ties were resolved through discussion.

Table 3.8: Sample coded transcript from Ms. Ransom's Group 1

Turn, Timestamp & Speaker	**Contribution (/utterance/)**	**Structure Code**	**Dialogic Code**	**Ties**
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 and Student 9*] 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

Creating valued directed matrices. Afterwards, I created valued and directed matrices (Carolan, 2014) of argumentation ties for both the structural and dialogic contributions from each science seminar. The term "valued" refers to the extent to which a tie between two actors did or did not exist (e.g., 7 = 7 utterances made toward a person, 0 = no utterances made toward a person), while the term "directed" refers to whether the comment was reciprocated. The dimensions of each matrix comprised of the students in a seminar group and the teacher (i.e., Ms. Ransom, Mr. McDonald or Ms. Allen), with each actor represented by both a row and column. Figures 3.2 and 3.3 below represent examples of what these matrices looked like, with Figure 3.2 illustrating ties for the code of "reasoning" and Figure 3.3 illustrating ties for the code of "critiquing." For example, reading the sample matrix in Figure 3.2 one sees that Ms. Ransom directed three reasoning ties to Student 2, but Student 2 never did so toward Ms. Ransom.

Recipient

		Ms. Ransom	Student 1	Student 2	Student 3	Student 4
	Ms. Ransom	0	0	3	0	0
	Student 1	4	0	1	1	2
Sender	Student 2	0	2	0	1	0
	Student 3	1	1	1	0	1
	Student 4	0	0	0	1	0

Figure 3.2: Sample valued and directed matrix for reasoning ties

Conversely, Student 3 was also coded as making a remark that included reasoning at Student 2, an action that was reciprocated by Student 2 during the science seminar. Figure 3.3 presents a different image. In terms of critiquing, this sample matrix illustrates that the teacher, Ms. Ransom, criticized all of the students' contributions at least once. However, most of the students were rarely coded as evaluating their peers' ideas. In fact, only one student (Student 3) was observed making critiquing remarks to other students.

Recipient

		Ms. Ransom	Student 1	Student 2	Student 3	Student 4
	Ms. Ransom	0	1	2	4	1
	Student 1	0	0	0	0	0
Sender	Student 2	0	0	0	0	0
	Student 3	1	2	1	0	1
	Student 4	0	0	0	0	0

Figure 3.3: Sample valued and directed matrix for critiquing ties

Carrying out the SNA and creating sociograms. These valued and directed matrices were then used to conduct the SNA with UCINET 6 (Borgatti, Everett & Freeman, 2006) software. This software program is recommended for people new to conducting SNA (Carolan, 2014), and includes NetDraw, a visualization tool with advanced graphing features. Specifically, I 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 provided 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 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. I 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. I created a sociogram for general participation to illustrate what is captured and lost by evaluating student engagement with this lens alone. This analysis resulted in a total of 54 sociograms (a subset of which are described in Chapters 4, 5 and 6; see Appendix E for all sociograms).

Central to SNA is the idea that the structure of the network, and one's position in it, is related to opportunities and outcomes (Carolan, 2014). The sociograms of the different science seminars showed whether particular types of interactions were occurring between all actors or whether some actors were communicating more, or less, with other group members (Haythornthwaite, 2002). The sociograms also highlighted individuals who were positioned in interesting ways in the network. This includes participants who were at the periphery of the network, central actors, or even people who served as bridges between some participants and the rest of the group. While individual actors and their relations between others are important, the impact of these relations on an intended outcome is influenced by the structure of the network in which they lie.

The benefit of using SNA to analyze the science seminars is that it allowed for a visualization of *what* happened with respect to the interactions amongst different classroom members during the discussion, which is not otherwise easily discernable. The sociograms derived from the SNA, which were used to answer the first set of research questions, revealed variation in how the different classrooms engaged in argumentation across the structural and dialogic aspects of this science practice. These differences subsequently prompted further analyses, which were guided by the second and third sets of research questions (see Table 3.5 for details). Next, I describe the analytic technique used to examine the second set of research questions.

Multiple Case Study Methodology

Rationale for the analysis. The sociograms from the SNA revealed similarities and differences across and within the classrooms in terms of how individuals engaged in the structural and dialogic components of argumentation. Prior research has found that the manner in which teachers frame argumentation tasks impacts how students understand and engage in this science practice (e.g., Berland & Hammer, 2012). Given this knowledge, and because of variation in how students partook in the science seminar, I decided to further examine the language around how teachers framed this particular argumentation activity. For this portion of the study, I only analyzed Ms. Ransom and Mr. McDonald's classes. I chose to examine these teachers – and did not include Ms. Allen – because they both worked at the same school, taught 7th grade students, and piloted the *Metabolism* unit. Thus, selecting only these teachers lessened the likelihood that differences amongst their students' seminars were due to factors related to the school and/or curricular context. Furthermore, Ms. Ransom and Mr. McDonald behaved similarly during the focal lesson: they both spoke most during the introduction to the activity, and very little during the actual seminars. Moreover, they both sat towards the back of the classroom, physically removing themselves from the discussion. Thus, for this analysis I only examined these teachers' introductions to the argumentation activity. This analysis was guided by the second set of research questions (see Table 3.1).

About this analytic approach. Multiple case study methodology (Stake, 2000) was used to make sense of the ways that Ms. Ransom and Mr. McDonald framed the science seminar activity. This case study (Yin, 2013) approach was an appropriate means to take for this analysis because it enabled me to more deeply examine these teachers' framing during the introduction to the focal lesson. Each teacher's classroom constituted one case; thus, two cases were analyzed in this portion of my dissertation study. This methodology also allowed me to develop qualitative descriptions of the phenomena of interest (Miles & Huberman, 1994); specifically, of the teachers' classrooms and of how they each articulated to students the participation framework (i.e., actions, and goals of the activity) for the science seminar. Additionally, because there were numerous cases of intrinsic interest (Stake, 2000) – Ms. Ransom's classroom and Mr. McDonald's classroom – multiple case study methodology provided a way for comparisons to be made across the classrooms as the teachers enacted the same curricular unit.

Conducting the multiple case study methodology. To create the two cases, one around each focal teacher's classroom, I analyzed the introductions to the science seminar activity in collaboration with another graduate student. The original transcripts of the three classrooms' science seminars were used to carry out this analysis. Specifically, to ground my exploration of the teachers' framing I used the notion of "participation frameworks" (Goffman, 1981; Goodwin, 1990). This concept is composed of two constructs: the actions individuals take during a particular type of activity, and the goals that drive the activity. Work on classroom discourse has examined the ways by which participation frameworks are established through talk (e.g., O'Connor & Michaels, 1993). As such, we employed open coding (Marshall & Rossman, 1999) to investigate how Ms. Ransom and Mr. McDonald used recurring language to convey the particularities of engaging in a science seminar to their students. Specifically, the constructs that make up a participation framework (i.e., actions and goals) helped guide the analysis of the language teachers used to frame this classroom task.

We read through the transcripts many times making notes and highlighting instances when we thought each of the teachers was articulating the participation framework for the science seminar. We first read Ms. Ransom and Mr. McDonald's introductions for language related to expected actions, and then in terms of how these teachers framed the purpose of the argumentation discussion. Additionally, after each reading of the transcripts, we wrote analytic memos (Miles & Huberman, 1994) of general trends that we were beginning to observe or ideas that came to mind from the analysis. These memos triggered further reflection to hone in the commonalities and differences between the teachers' framing. To find patterns across the classrooms, we then grouped each of the highlighted words or phrases by teacher, and construct (e.g., all of the instances when Ms. Ransom articulated an action she expected students to engage in during the argumentation discussion). Both readers made notes of these trends, and afterwards we compared our notes of the actions and goals that we saw the focal teachers describing. Any disagreements that arose were resolved through discussion. This iterative process resulted in final trends that described how the two teachers framed the argumentation discussion to their students.

The trends that captured how the teachers framed student actions and the science seminar's purpose were then compared to each classrooms' sociograms across the structural and dialogic components of argumentation. In looking through the sociograms and reading the varied classroom descriptions, we noticed that one particular type of interaction (namely, building on other's ideas), was vastly different in Ms. Ransom and Mr. McDonald's classrooms. Subsequently, in Chapter 5, this difference is discussed in relation to the two teacher's framing of the goals for this argumentation activity.

Discourse Analysis

Rationale for the analysis. Dominant interactional patterns in science classrooms (e.g., initiate-response-evaluate; Lemke, 1990) minimize opportunities for students to critique their peers' ideas (Henderson et al., 2015). Moreover, research in argumentation has documented that critique is an aspect of this science practice that may be particularly challenging for students (Ford, 2012). Yet, the SNA revealed that three of the groups' seminars included high instances of students critiquing their peers' ideas during the argumentation discussion. Specifically, these groups included: Ms. Ransom Group 2, Ms. Allen Group 1 and Ms. Allen Group 2. As a result, I further examined these groups' seminars to more deeply understand what interactional moves may have prompted students to engage more in critique during these discussions than in the others. This analysis was guided by the third set of research questions (see Table 3.1 for details).

About this analytic approach. Language, either in written or spoken form, is the subject of interest and examination when conducting discourse analysis (DA). The underlying idea of this methodology is that people use language to *do* things (Potter & Wetherell, 1987). In the case of argumentation, the things people do with language include all of the processes that they engage in as they construct, refute and revise a claim about a science phenomenon. Of particular focus is how language is used to accomplish certain tasks. As such, discourse analysts are interested in the ways that language is organized, and the subsequent consequences of organizing language one way as opposed to another (Potter & Wetherell, 1987). For this analysis, I was particularly interested in how language was used to encourage instances of student critique. Investigating interactional moves provides insight into how individuals are positioned in alignment with each other, or in opposition with one another (O'Conner & Michaels, 1993). This was necessary to consider within the context of a science seminar, as during the debate students were meant to notice the similarities and differences between contributions, to critique differences, and to build upon previous ideas. However, if language is being used such that students do not understand their roles to include critique, then they may not engage in this type of action.

Preparing the data for analysis. Although the same underlying transcript (i.e., including the information described in the Data Source section) was used to conduct the SNA, multiple case study methodology, and DA, these transcripts were not identical, as different levels of detail were needed for each analytic approach. Specifically for the DA, the transcripts were not broken down at the utterance level. Instead, these versions were more nuanced, including detailed information about the conversation. Table 3.9 includes the transcription conventions described by Atkinson and Heritage (1984) that I used to explore the sequences of turns around student critique during the science seminar.

Table 3.9: Transcription conventions (adapted from Atkinson & Heritage 1984)

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

These particular conventions were important to include in the transcriptions because they correspond to common occurrences during large group debates, such as people speaking over one another or cutting another person off; palpable moments of silence; someone whispering because they are hesitant to share an idea; or an individual speaking loudly to sound more persuasive. Furthermore, certain conventions, such as (), were included to account for the realities of transcribing (it can be difficult to correctly hear all contributions during a video recording of a conversation).

Conducting the discourse analysis. Because the science seminars were relatively short in length, a graduate student and I read through all of the focal groups' transcripts, instead of only analyzing portions of the discussions. Each transcript was initially read with an unmotivated lens (Gee, 2005), which gave us the opportunity to obtain a general feel for how the science seminar went, including the ideas that were discussed, and what (if any) conclusions were made. Afterwards, subsequent readings of the text were guided by questions that aligned with the goals of this portion of the dissertation, which were to better understand the interactional moves that helped create circumstances in which students engaged in critique. These guiding questions included: How are classroom members using language around instances of critique? Are only the teachers prompting for critique or are the students also involved in this process? Does an individual need to engage in critique themselves in order to prompt another to do the same? Are instances of critique always followed by other critiquing remarks? Is one person, or are multiple people, carrying out interactional moves that encourage critique? In addition, because language is used to accomplish intricate social processes (in this case critique during the science seminar activity), we used analyzable features of the argumentation discussion to answer these questions, including the markers described in Table 3.9.

Furthermore, it is important to point out that transcripts are inherently incomplete accounts of a conversation because they tend to include information about areas that are of particular interest to the researchers (Duranti, 1997). In the case of my dissertation, these transcripts included details about some elements of talk (e.g., overlapping speech) while leaving out other aspects (e.g., intonation). Thus, it was sometimes necessary to return to the transcripts to add additional markers, which allowed for new insights to emerge when reanalyzed. For example, one such marker that was added, and then resulted in us re-reading the transcripts was when speakers sped up or slowed down their speech – an action that ended up being part of one of the interactional moves around critique that we recognized.

For each guiding question, we read through the focal seminars' transcripts multiple times, looking for instances that exemplified the phenomena of interest, and selected transcript extracts that illustrated that feature. It was important to keep in mind whether these extracts represented a phenomenon that occurred numerous times throughout the seminar, or whether it was an exception. Considering such situations resulted in an understanding of how each seminar was carried out in terms of student critique. We also jotted down analytic memos (Miles & Huberman, 1994) of our thought process as we engaged in these tasks; this helped us recall why we made particular decisions during the analysis. In terms of reliability, any time that a selection process took place during this analysis a second reader (i.e., the other graduate student) corroborated the selection. For instance, this occurred when extracts were compiled to illustrate a particular interactional move that engendered critique. This analysis resulted in us identifying four interactional moves – two conducted by one teacher, Ms. Allen, and the other two conducted by students across the three focal seminars – that stimulated student engagement in critique.

Summary

This chapter described the methodological approaches that I took to analyze the three classrooms' transcripts from the science seminar activity. The mixed methods approach, which consisted of SNA, multiple case study methodology, and DA, was selected to explore multiple facets of these argumentation discussions, as guided by the different sets of research questions (see Table 3.1). Specifically, these different analytic techniques offered insight into: the interactional patterns during each group's seminar in terms of the structural and dialogic components of argumentation, the different ways that teachers framed the participation framework (i.e. expected actions and intended goals) for the science seminar task, and teacher and student interactional moves that stimulated instances of critique. The three results chapters that follow are organized around each set of research questions (see Table 3.5 for details).

Chapter 4 – Visualizing Interactional Patterns of Scientific Argumentation Through Social Network Analysis

In order to identify the similarities and differences between the three classrooms' argumentation discussions, I began by conducting a social network analysis (SNA) of the science seminar transcripts. The resulting sociograms from the SNA allowed me to develop a richer understanding of the degree to which the teachers and students participated in the oral argumentation activity. Moreover, this analysis enabled me to address the following research questions:

- How are the structural and dialogic components of argumentation represented in three middle school science classrooms?
- What interactional patterns do sociograms highlight in the argumentation discussions?

The SNA revealed variation across the six groups. This chapter is organized to discuss these differences, starting with an overview of the six science seminars. Beginning more broadly, I first offer information about each seminar in terms of duration, number of turns of talk and utterances, as well as the breakdown of teacher and student contributions. I also highlight the ways that the seminars compared in terms of frequency of the structural and dialogic components of argumentation. This is followed by an in depth discussion of a subset of sociograms. I do not present all 54 sociograms from the SNA (see Appendix E). Instead, I use a selection of sociograms from Ms. Allen and Mr. McDonald's classes as examples to illustrate how SNA can be used to map interactional patterns during argumentation discussions. These sociograms enabled me to examine similarities and differences across and within the classrooms regarding the teachers' and students' use of argument structure and engagement in dialogic interactions.

Analysis of the Six Science Seminars Using Counts and Frequencies

Before delving into some of the sociograms that came out of the SNA, I first discuss the ways that the science seminars in the three classrooms were alike and unlike one another in terms of counts and frequencies. Table 4.1 offers a glimpse into the 6 debates (2 from each teacher's classroom). Specifically, this table includes information about the duration of each seminar, the number of turns of talk during each argumentation discussion, as well as the amount of utterances encompassed within these turns of talk. Recall that I conceptualized an utterance as a unique idea or contribution to the discussion (see Chapter 3 for specific coding schemes and example utterances). Thus, depending on the number of ideas presented, a single turn of talk could encompass one or multiple utterances.

As seen in Table 4.1 the discussions varied in length, averaging 10 minutes. While the shortest seminar lasted 9 minutes and 16 seconds (Group 1 in Ms. Allen's class), students spoke for 17 minutes and 53 seconds during the longest discussion (Group 2 in Ms. Allen's class). Furthermore, the frequency of contributions was wide-ranging, with Mr. McDonald's seminars having the least number of turns of talk (56 in Group 1 and 42 in Group 2), and Ms. Ransom's Group 2 having the most number of turns of talk (130). Given that the discussions in Mr. McDonald's class were not noticeably shorter than the average length of the seminars across the three 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.

Furthermore, out of all the seminars, Ms. Allen's Group 2 had the most utterances (269), while Mr. McDonald's Group 2 had the least (113). I now turn to discussing these utterances in terms of the classroom members who made them (teacher or students), as well as how they were coded across the structural and dialogic components of argumentation.

Table 4.1: Breakdown of science seminars

Teacher and Group		**Duration**	**Turns**	**Utterances**
Ms. Ransom	Group 1	11 minutes, 59 seconds	95	161
	Group 2	10 minutes, 6 seconds	130	185
Mr. McDonald	Group 1	10 minutes, 33 seconds	56	134
	Group 2	9 minutes, 34 seconds	42	113
Ms. Allen	Group 1	9 minutes, 16 seconds	114	205
	Group 2	17 minutes, 53 seconds	119	269

Classroom Member Contributions

Figure 4.1 illustrates the breakdown of utterances across classroom members in the three focal classes. Overall, students were observed contributing most during the activity, averaging 83% of the total utterances across all of the 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), the teachers would have had more utterances. That said, compared to the other two teachers, Ms. Allen was more involved during her students' argumentation discussions. Specifically, across both Ms. Ransom and Mr. McDonald's seminars the teachers averaged approximately 12% of the total utterances. Meanwhile, on average, Ms. Allen's utterances made up nearly 27% of her students' seminars. The role Ms. Allen played in her students' debates is discussed further in Chapter 6. Additionally, it is important to note that while Figure 4.1 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, it does not illustrate to whom comments were directed (i.e., Where students speaking mostly to their peers, to the teacher, or to a combination of both?).

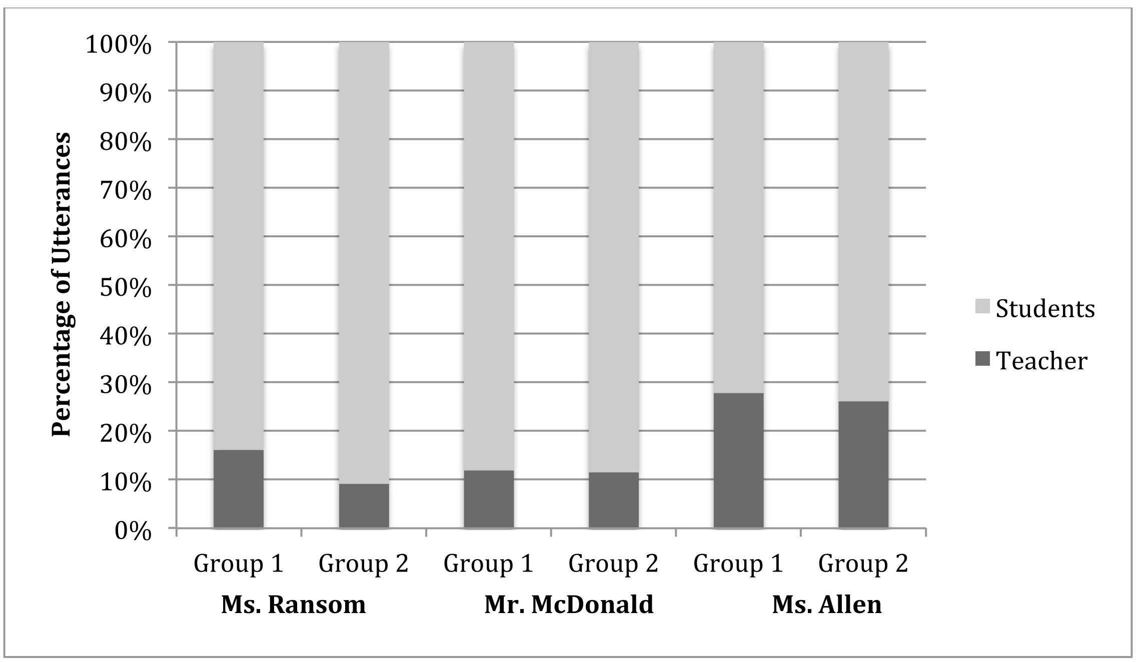


Figure 4.1: Breakdown of utterances across classroom members

Argument Structure and Dialogic Interactions

The argumentation breakdown across the groups' seminars for both argument structure and dialogic interactions can be seen in Figure 4.2 and Figure 4.3. These figures include utterances made during the science seminars by both teachers and students. Although these figures could have been further broken down by teacher and student utterances, it was unnecessary to do so to illustrate the nature of the argumentation discussions (especially since the teachers spoke relatively little). As such, these representations highlight the frequency of the different aspects of argumentation. Examining Figure 4.2 first, one sees that classroom members generally attended to the structural components of an argument (i.e., claim, evidence, and reasoning), although to varying degrees. For example, compared to Ms. Ransom and Mr. McDonald's classes, more utterances in Ms. Allen's classroom were coded as relating to a claim. Yet, differences in argument structure also occurred within the same teacher's classroom. For instance, Group 1 in Ms. Ransom's class discussed evidence much more than Group 2.

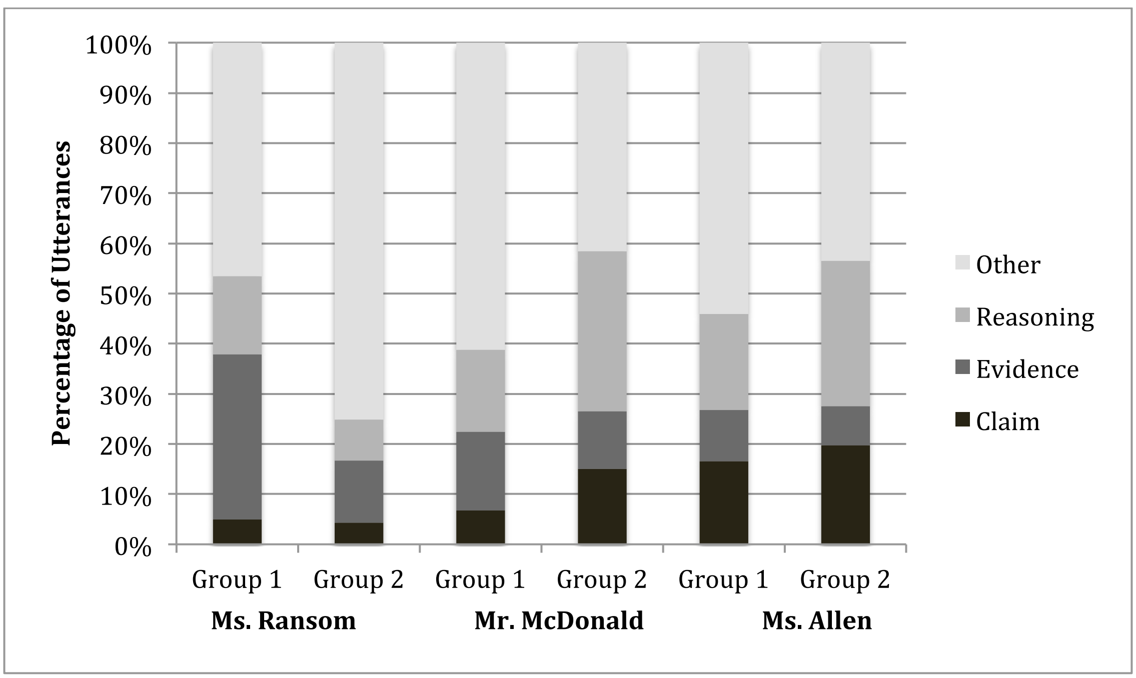


Figure 4.2: Breakdown of utterances across argument structure codes

It is worth commenting on the code of “Other,” which across all six seminars made up nearly 54% of the total utterances. Although a large percentage of the discussions were comprised of these types of utterances, this is not unexpected. Students were doing more than presenting their claim, evidence and reasoning during this activity; 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 (e.g., asking a question). For example, there were occasions during which a student disagreed with a peer’s contribution (e.g., “I don’t agree with you”). Also, for an utterance to receive a structural code it had to relate directly to the subject matter being debated, and sometimes students’ discussions veered slightly off topic. For instance, during the Ms. Ransom Group 2’s seminar, students discussed the validity of the data, and one student commented that “maybe the scientists wanted to give misleading data.”

Figure 4.3 illustrates how the seminars compared across the dialogic aspects of this science practice (i.e., questioning, critiquing, and building off other’s arguments). Each utterance from the seminar was coded across both argumentation coding schemes. For example, 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. Overall, in contrast to the structural codes, across the three classrooms utterances frequently included individuals engaging in these types of discursive moves. Specifically, (averaging across all six science seminars) about 46% of utterances were coded as argument structure, while almost 63% were coded as dialogic interactions. This suggests that some of the “Other” statements for argument structure were students building on, critiquing or questioning the ideas of a peer. Additionally, unlike argument structure, there was more variation between how the teacher and students in the different classrooms interacted with each other's ideas. For instance, while Ms. Allen's students tended to challenge and critique their peers more frequently, Mr. McDonald's science seminars included more individuals building on other's arguments.

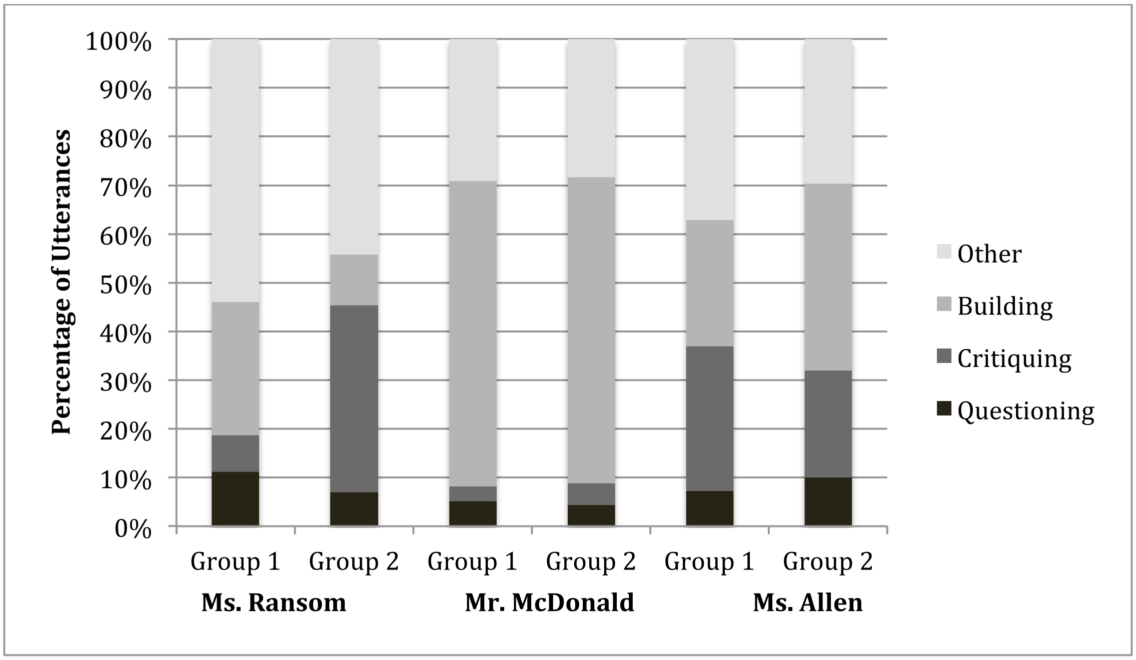


Figure 4.3: Breakdown of utterances across dialogic argumentation codes

Table 4.1 and Figures 4.1 – 4.3 are helpful for identifying commonalities and differences amongst the six science seminars in terms of the frequencies of different types of utterances. These ways of presenting findings from analyses of classroom discussions has been successfully used in previous argumentation research to illustrate the breakdown of discussions across claim, evidence and reasoning (e.g., McNeill & Pimentel, 2010), and across particular dialogic moves, such as questioning and evaluation (e.g., Berland & Reiser, 2011). In the following section, I present a different way to capture engagement in this science practice, demonstrating how a combination of representations can paint a fuller picture of argumentation experiences.

Visualizing Interactional Patterns Through Sociograms

In this section, I analyze the same data (i.e., the science seminar transcripts) using SNA to map the interactional patterns that took place during the argumentation discussions. Analyzing the same data with a different technique highlights the affordances and constraints of the different methodologies. 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's group's science seminar (Mr. McDonald's Group 2), to demonstrate the ways this analytic technique can be used to examine variation within and across different classrooms. Visualizing engagement in argumentation via sociograms is informative as it sheds light on how individuals partake in the different aspects of this science practice; insight that is not captured through more common methods of analyses (e.g. frequency tables, such as those presented in Figures 4.2 and 4.3).

Analysis Within One Group

In this subsection I provide and discuss a variety of sociograms – starting broadly (e.g., sociogram of all interactions) and then narrowing the focus (e.g., sociogram of questioning) – to illustrate how SNA can be used to visualize particular aspects of argumentation engagement. The sociograms I use to exemplify this utility come from Group 2 in Ms. Allen's classroom.

Sociograms of general interactions. 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 the sociograms that I created as part of this dissertation study, the nodes are either a teacher (the red circle) or students (blue diamonds), while the ties, which may or may not be directional, capture the type of argumentation interaction being focused on (e.g., utterances of questioning, or utterances that included reasoning). I will now highlight elements that are central to making sense of a sociogram by discussing the sociogram that was created of the general participation of classroom members during the focal group's science seminar (see Figure 4.4). General participation included all utterances spoken throughout the science seminar (including, "Who would like to be discussion leader?" and "I have nothing else to say"), not just those captured by one of the codes for argument structure or dialogic interactions.

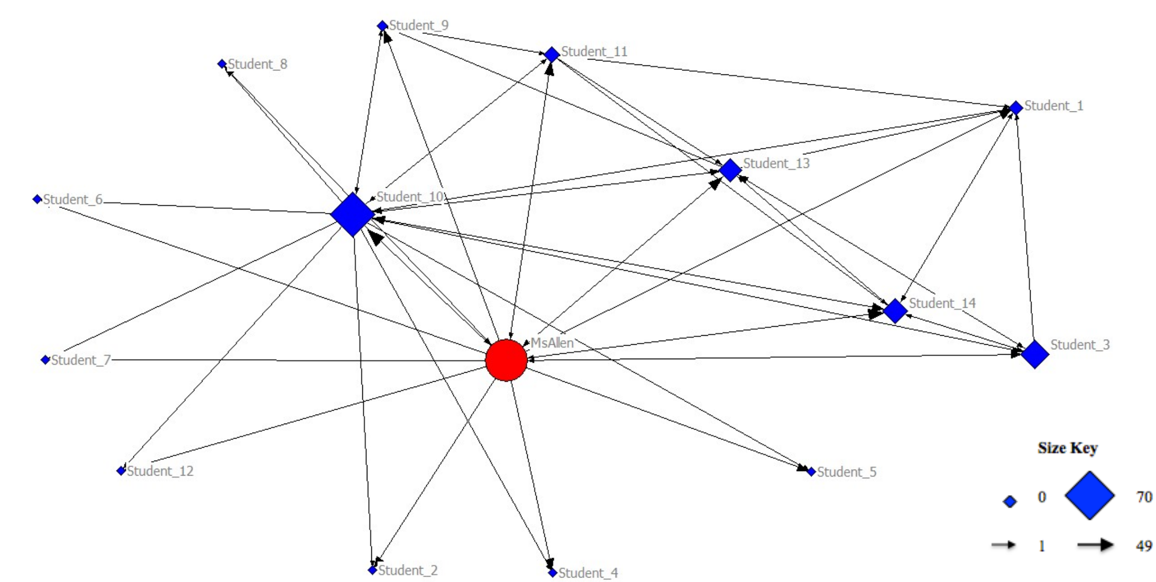


Figure 4.4: Sociogram of general participation in Ms. Allen's Group 2

In sociograms, 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 4.4 is generally speaking during the debate. In this group's discussion, the least number of times that an individual spoke was zero, while 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. Specifically, these individuals contributed 38, 28, and 31 utterances respectively.

It is also important to examine the ties in a network, which are represented by the arrows between actors. For this dissertation study, the ties include information about how classroom members interacted with each other during the seminar (i.e., who directed an utterance at who?). Figure 4.4 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 towards all individuals in the group. There were also classroom members who never made remarks to one another during the entire argumentation activity, such as Student 5 and Student 3, which is apparent by the lack of ties between them. Moreover, while some arrows are double headed, meaning ties were made in both directions (see Student 10 and Student 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 are indicative of the number of times a particular tie was made between actors (see key in Figure 4.4). Thus, while some individuals only spoke 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 Student 10 and Student 13, to whom she directed 49 and 35 utterances respectively.

The type of summary captured in Figure 4.4 would be akin to the information presented earlier in Table 4.1 and Figure 4.1, which generally overviewed the teacher and students' engagement in the science seminar. However, the sociogram of general participation looses the particularities detailed in Table 4.1 and Figure 4.1, such as the duration of each seminar, and the breakdown of the argumentation discussion across teacher and student utterances. Nonetheless, Figure 4.4 does highlight the exact classroom members that participated in the argumentation discussion; this level of detail is not evident in representations focused on frequency of teacher and student involvement (i.e., Figure 4.1).

While 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 of this science practice. For instance, it does not offer us insight into who supported their arguments with evidence, or who questioned another person's idea during the debate. Moving towards this level of detail, I now turn to discussing the sociograms that were created for dialogic interactions.

Sociograms of dialogic interactions. Figure 4.5 illustrates the dialogic interactions that took place during the second group's science seminar in Ms. Allen's class. All utterances that were coded "Other" for dialogic interactions, however, are not included in this sociogram. Thus, the sociogram in this figure encompasses when an individual asked a question, critiqued someone's contribution, and also when a participant built off of another person's idea (see Table 3.6 for details).

With this lens, I can make 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 Figure 4.4 and Figure

4.5, and examining the size of nodes in the sociograms, one can see that similar individuals stand out as having engaged in more dialogic interactions. Again Student 10 has the largest node, having made 54 utterances that captured the argumentation interactions of interest. Ms. Allen's node, although still large (27 utterances), is no longer equally as dominant as this particular student, which means the teacher less frequently partook in dialogic interactions. Others also engaged often in these discursive moves, including Students 1, 13, 14, and 3, who contributed 13, 26, 28 and 32 utterances respectively across these types of argumentation interactions.

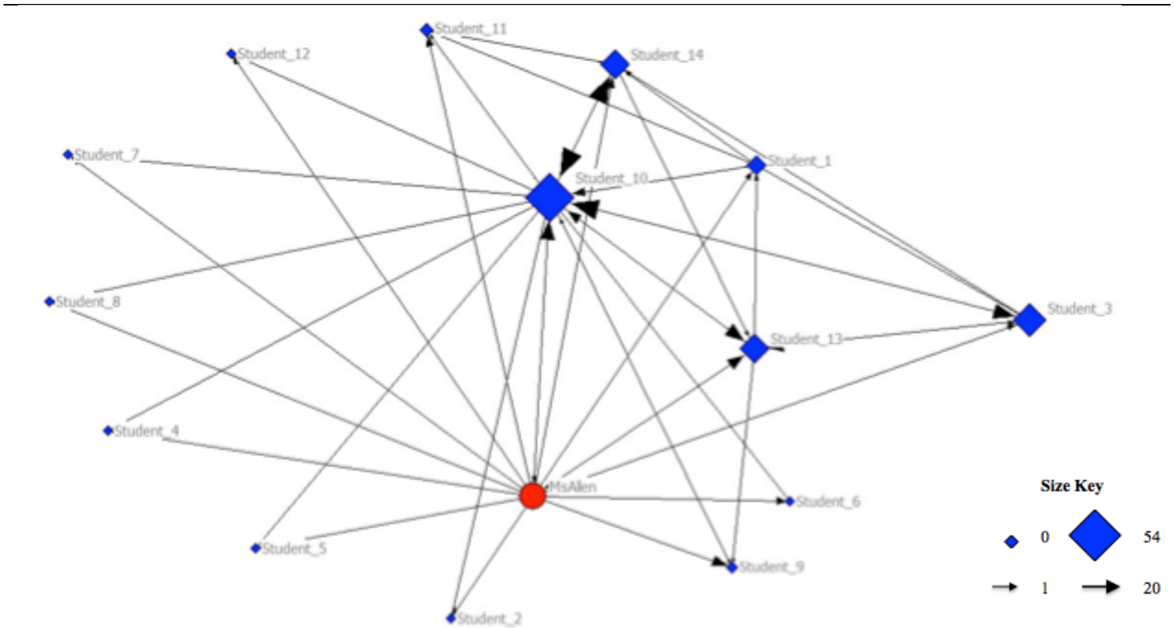


Figure 4.5: Sociogram of dialogic interactions in Ms. Allen's Group 2

Focusing on the ties in Figures 4.4 and 4.5, it is interesting to note that in both of the sociograms Ms. Allen and Student 10 have ties to all of the participants. Although some of Student 10's dialogic ties were reciprocated (by the teacher, as well as by Students 1, 3, 9, 13, and 14), most of Ms. Allen's dialogic ties were unidirectional. This means that students tended to not direct utterances that were coded as dialogic interactions towards their teacher. Furthermore, as seen by the amount 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.

While this lens offers more information about the dialogic argumentation that took place during the science seminar of Ms. Allen's Group 2 – especially in comparison with the sociogram of general participation – from Figure 4.5 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 Student 10 and Student 3 mainly encompassed utterances of these students critiquing one another, or asking each other questions. Consequently, I now hone in more on these interactions, specifically highlighting individuals' engagement in questioning.

Sociograms of questioning. Figure 4.6 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, evident by the size of their nodes (both participants had 10 utterances coded as "Questioning"), as well as the number of ties they have radiating 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 4.5 we know that Student 10 produced 54 utterances that were coded as dialogic ties. Given the information in Figure 4.6, it is now clear that nearly 20% of these ties included this student questioning their peers, which means the other 44 utterances were of them “Critiquing” and/or “Building”. This sociogram also shows that overall students in this group did not often question other’s ideas during their science seminar. Yet, this representation alone does not portray what percentage of the discussion included “Questioning”. However, from Table 4.3 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 4.6, it becomes clear that most students (specifically 10 out of 14) were recipients of questions, but themselves did not ask any. This illustrates the strengths and weaknesses of the different representations and how they can be used together to develop deeper understandings of argumentation engagement.

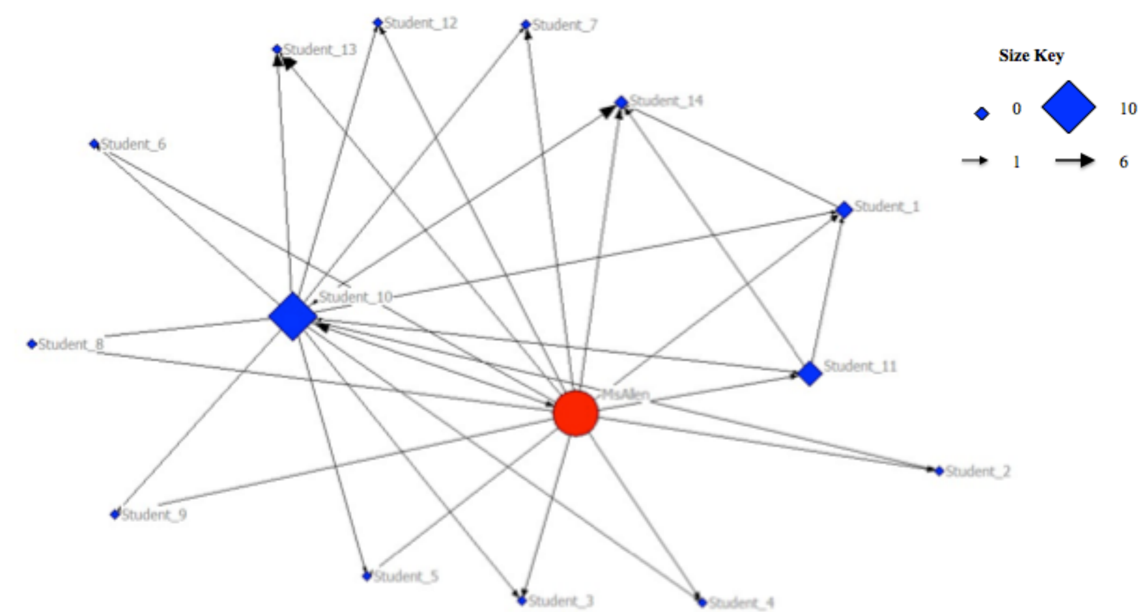


Figure 4.6: Sociogram of questioning in Ms. Allen’s Group 2

Each of the sociograms that I have presented and discussed thus far has provided a more nuanced description than the one before it of the argumentation that took place during Group 2’s science seminar. Starting with Figure 4.4, I was able to show who generally participated in this activity. The sociogram that followed provided information on classroom members' dialogic interactions. However, given the grain size, it was unclear exactly which discursive moves the students and teacher engaged in (i.e., questioning, critiquing and building on other's ideas). Then, I sharpened the focus of the visualizations even more, showing and describing the sociogram of questioning. As exemplified by these figures, sociograms are able to illustrate who engaged in the argumentation discussion, and how – information that cannot be obtained from bar graphs alone (i.e., Figures 4.2 and 4.3). 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 or building on other's ideas). However, as I have demonstrated, merging the information offered by different representations provides greater insight into how the teacher and students partook in the science seminars.

I now briefly go through these same steps for argument structure, in order to demonstrate how SNA can also be employed to highlight this component of argumentation. While other studies have analyzed and described the claim, evidence and reasoning in students' spoken and written arguments (e.g., Erduran, Simon & Osborne, 2004; McNeill et al., 2006), this work shows argument structure *in use*. For example, as I illustrate shortly, sociograms can show which students are providing reasoning, how many of these students' utterances encompass reasoning, and to whom students direct their reasoning utterances.

Sociograms of argument structure. Again, beginning more broadly, Figure 4.7 captures how the classroom members used argument structure throughout the science seminar. All utterances that were coded "Other" for argument structure are not included in this sociogram. As such, this particular sociogram encompasses when an individual's utterance included a claim, evidence or reasoning (see Table 3.5 for details). Given the size of nodes, five students (specifically, Students 1, 3, 10, 13, and 14) and Ms. Allen appeared to have contributed the greatest amount of argument structure ties. Specifically, Student 10 offered the most (with 46 argument structure utterances), followed by Students 3, 14, 13, the teacher and Student 1 (with 28, 25, 22, 12 and 11 argument structure utterances respectfully).

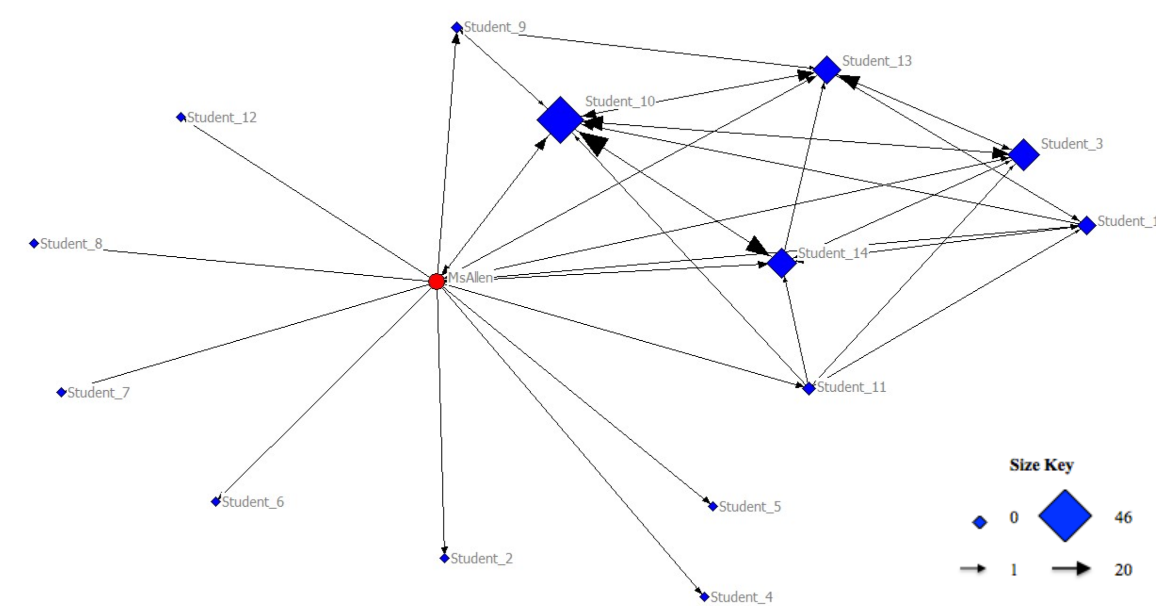


Figure 4.7: Sociogram of argument structure in Ms. Allen's Group 2

Similar to the other sociograms presented thus far, Ms. Allen had argument structure ties to every student in the group. Also, there were students who did not direct these types of ties toward a peer (e.g., Students 6 and 7 or Students 12 and 8), which is apparent by the lack of ties between them. Furthermore, a small sub-group of students (top right of the sociogram) seems to have formed with respect to this argumentation component. These students exchanged many ties related to argument structure amongst themselves. For instance, Student 10 directed 16 argument structure ties at Student 14, who reciprocated the gesture with 20 argument structure ties. However insightful this sociogram is with regards to the classroom members' use of argument structure during the science seminars, it is unable to provide specific information about this argumentation component. For instance, it is unclear with this sociogram alone whether Students 10 and 14 exchanged utterances related to a claim, evidence and/or reasoning. For this level of detail, I now turn to the next sociogram.

Sociograms of reasoning. Figure 4.8 illustrates how members of Ms. Allen's Group 2 used reasoning during the science seminar. This sociogram is a bit different from the others discussed thus far, mainly due to it including fewer individuals because many of the students did not offer reasoning, nor was an utterance that contained reasoning tied to them. These individuals' names are listed on the top left corner of the sociogram.

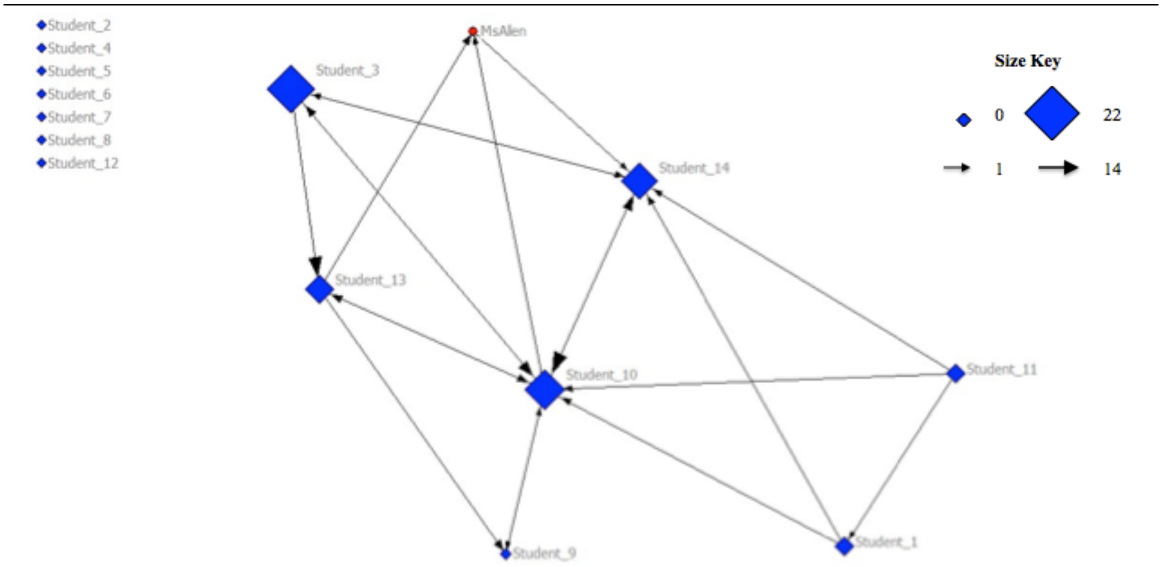


Figure 4.8: Sociogram of reasoning in Ms. Allen's Group 2

Specifically, half of the students (7 out of 14) did not produce an utterance that was coded as “Reasoning,” nor did a classroom member direct a reasoning utterance toward them. Moreover, from Figure 4.2 we know that 29% of this seminar’s utterances were coded as “Reasoning”, which was more than any of the other structural codes (19.7% were “Claim” and 7.8% were “Evidence”). Combining this known percentage with the sociogram below, we now know which individuals were responsible for providing these reasoning ties. Again, this type of deduction points to the advantage of using multiple forms of representation. Of the classroom members that were involved with reasoning, students appeared to have contributed more reasoning utterances than the teacher. Examining the size of the nodes, one sees that Student 3 offered the most (with 22 reasoning utterances), followed by Students 10, 14 and 13 (who had 18, 15 and 11 reasoning utterances, in that order). Further, it is interesting to point out that the students identified within the sub-group of the argument structure sociogram (see top right of sociogram in Figure 4.7) are many of the same active students in Figure 4.8. Additionally, compared to Ms. Allen’s involvement in other aspects of the discussion, such as her role in questioning (see Figure 4.6), the teacher was more of a minor actor with respect to the structural aspects of argumentation, especially in terms of reasoning.

Focusing on the ties within this sociogram, it is clear that while some individuals received many reasoning ties, others did not. For instance, six different students directed an utterance coded as “Reasoning” towards Student 10. On the other hand, Student 11 was the recipient of no reasoning ties, although they themselves produced some.

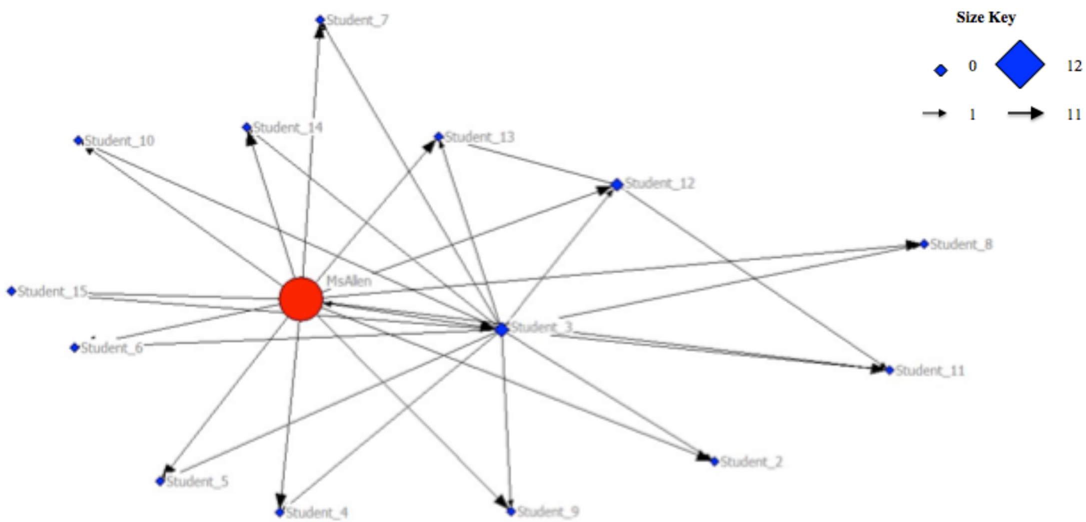
In this section of the chapter I illustrated how SNA can be used to highlight interactional patterns with respect to the structural and dialogic components of argumentation. Specifically, I showed sociograms at different grain sizes (e.g., general participation, all dialogic interactions, questioning) in order to demonstrate how narrowing the focus of the analysis enables a better understanding of the interactions that took place during the argumentation discussions. Unlike the descriptives presented earlier in the chapter (i.e., Figures 4.1 – 4.3), these sociograms provided more details about *who* engaged in particular aspects of this science practice, and *how*. However, in taking this deep dive and teasing apart the sociograms, one looses perspective of how each focal tie relates to other aspects of argumentation. Consequently, this points to the advantage of using multiple representations to examine argumentation engagement (as depicted in this section).

Variation Within and Across Classrooms

Overall, I created 54 sociograms as part of this dissertation study, 9 for each of the six science seminars. Specifically, for each argumentation discussion a sociogram was made for general participation, all argument structure, all dialogic interactions, claim, evidence, reasoning, questioning, critiquing, and building off other's ideas (see Appendix E). In this section I discuss how these sociograms were used to look for similarities and differences across and within classrooms, particularly in terms of the structural and dialogic components of argumentation. I illustrate this process using one within class example and one across classrooms example. The sociograms presented in this section, which come from Ms. Allen and Mr. McDonald's classroom, were intentionally selected so as to not overlap with the other result chapters.

Analyzing Questioning Within a Classroom. To demonstrate how sociograms can be used to examine variation within a classroom, I will focus on the dialogic interaction of questioning in the context of Ms. Allen's class. Figure 4.9 encompasses the two sociograms that were created to illustrate how the groups in Ms. Allen's class partook in questioning during their science 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 4.3 for further details).

Ms. Allen Group 1



Ms. Allen Group 2

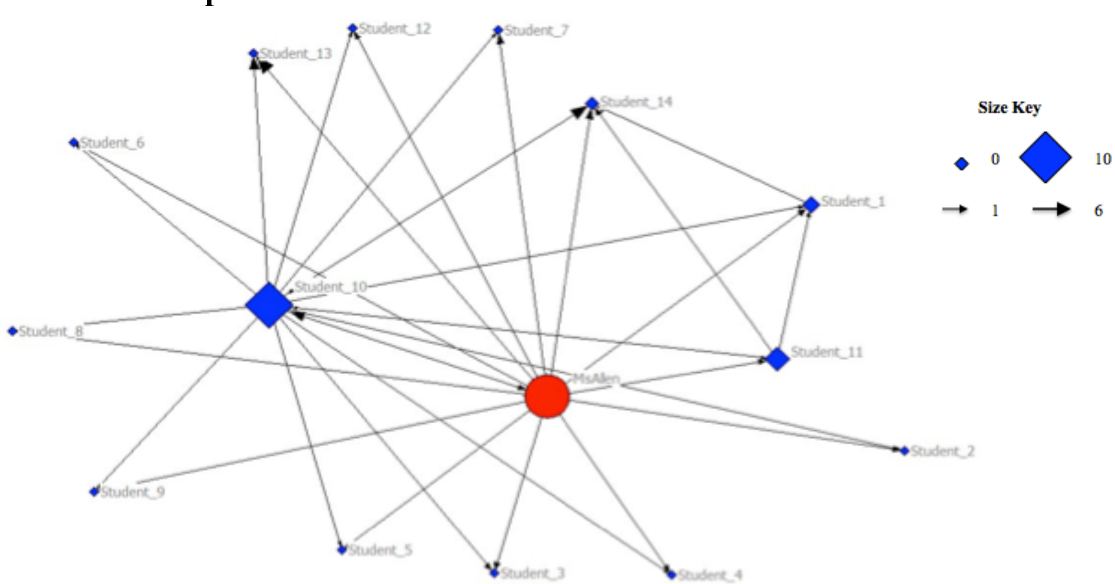


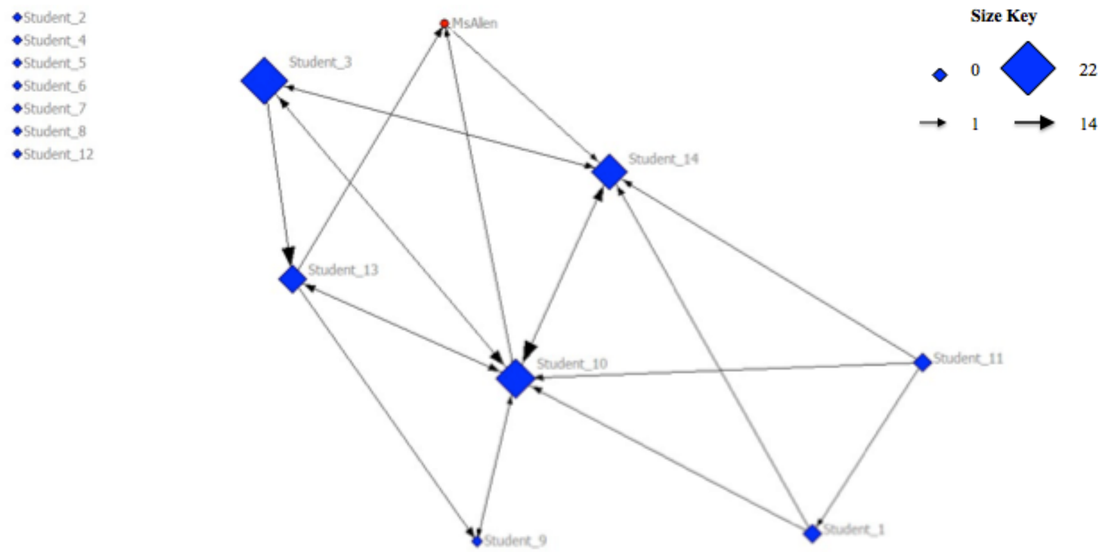
Figure 4.9: Comparing sociograms of questioning within a classroom

In both sociograms, Ms. Allen and one other student (namely 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 in the sociograms to look like the axle to the spokes of a wheel). Given the size of her node, the teacher was a dominant actor in both groups' seminars with respect to questioning. Additionally, across both groups very few students asked questions to their peers, as seen by the lack of ties between most students. 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 the two science seminars in Ms. Allen's classroom.

Analyzing Reasoning Across Classrooms. In this next example, I show how sociograms were also used to explore variation in the different classrooms. Figure 4.10 illustrates how individuals in Ms. Allen's Group 2 and Mr. McDonald's Group 2 used reasoning during their science seminars. The amount of utterances from these groups' discussions coded as "Reasoning" were also quite similar. Specifically, 29% of the utterances from Ms. Allen's group contained reasoning, while 32% of Mr. McDonald's group's debate included students articulating their reasoning (see Figure 4.2 for details). However, despite similar amounts of reasoning ties, these group's interactional patterns around this argument structure code differed (see sociograms in Figure 4.10).

As discussed in the previous section, 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 4.10). On the other hand, all of the classroom members in Mr. McDonald's Group 2 were somehow involved with this element of argumentation.

Ms. Allen Group 2



Mr. McDonald Group 2

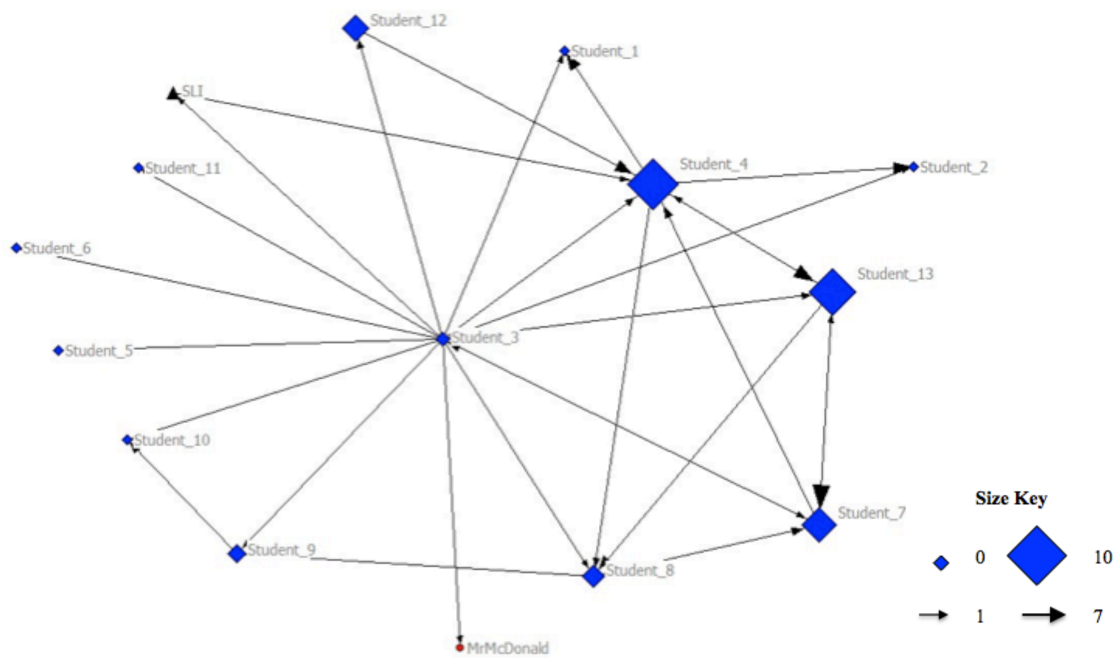


Figure 4.10: Comparing sociograms of reasoning across classrooms

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.

For example, Student 10 from Ms. Allen's class produced the most reasoning ties (22), and the maximum reasoning utterances directed from one student toward another were 14 (by Student 14 to Student 10). Meanwhile, Student 4 produced the most utterances coded as "Reasoning" in Mr. McDonald's group (specifically, 10 utterances), and Student 13 had the highest amount of reasoning ties with Student 7 (7). Therefore, although these groups' reasoning contributions appeared similar in Figure 4.2, the manner by which classroom members *used* reasoning was actually quite different. In one case fewer students articulated reasoning, but at higher frequencies, while in the other case more students made or received reasoning ties, but at lower frequencies.

Summary

Research in the field of argumentation has traditionally used the process of "coding and counting" (Sampson, 2016) to analyze and describe students' engagement in this science practice. This methodological approach includes quantifying particular aspects of interest, such as student questioning, and reporting upon these aspects in ways similar to Table 4.1 and Figures 4.1 – 4.3. This strategy is informative for illustrating the breakdown of classroom discussions across the various components of argumentation. Not only does this type of representation show how much of an argumentation discussion included particular aspects of this science practice (e.g., claim, evidence and reasoning), but it also allows for a comparison across these different aspects (i.e., how did students' use of evidence compare to their articulation of reasoning?). Furthermore, as mentioned earlier, this form of representing findings has been successfully used in prior argumentation research to highlight similarities and differences between different classrooms (e.g., McNeill & Pimentel, 2010).

However, this approach alone does not capture the full extent of these argumentation experiences (e.g., Are students engaging in the task equally? Are different students involved in using argument structure versus partaking in dialogic interactions?). As I demonstrated throughout this chapter, SNA allows us to go beyond "coding and counting," by mapping out the interactional patterns across both the structural and dialogic components of argumentation. The various sociograms uncovered *who* exactly was engaged in the various aspects of this science practice, *how* they were engaged, and to *what degree*. This technique could be beneficial to researchers interested in exploring particular interactional characteristics of argumentation discussions, such as the patterns of individuals who are primarily asking questions. Further, this methodology would be helpful for examining engagement of specific student groups. For instance, the student nodes could be further color-coded to demarcate gender or race, which could be interesting for someone who wants to explore whether a relationship exists between these factors and particular discursive moves (e.g., Are female students primarily senders or recipients of critiquing ties?). However, as I discussed in this chapter, although sociograms have some advantages over other methodologies, they also have limitations; this is where a combination of representations can be particularly insightful.

In the case of my dissertation, the resulting sociograms provided a more nuanced understanding of the similarities and differences between the three classrooms' science seminars. The richer understandings of these argumentation discussions led to further questions and analyses. In Chapters 5 and 6, I present findings from subsequent studies that came about as a result of examining all of the sociograms and conducting additional analyses.

Chapter 5 – Individual Versus Communal Understanding:

Varying Goals in Argumentation Discussions

In light of classroom variation in how students partook in the science seminar, I further investigated how teachers framed this particular argumentation activity. I chose to analyze only Ms. Ransom and Mr. McDonald's classes because they taught in similar environments (i.e., 7^{th} grade students in the same school, and they both piloted the *Metabolism* unit), mitigating potential differences in school context or curriculum that could be present if I included Ms. Allen's class. I concentrated my analysis on teachers' framing during the introductions to the science seminar because the teachers did the most work setting up the argumentation activity during this portion of the lesson; Ms. Ransom and Mr. McDonald spoke very little throughout their students' actual science seminars.

To ground my exploration of the teachers' framing of the science seminar I used the notion of "participation frameworks" (Goffman, 1981) as discussed previously in Chapter 2 and Chapter 3. This notion informed my investigation of how Ms. Ransom and Mr. McDonald used language to convey the particularities of engaging in a science seminar to their students. Specifically, the constructs that make up a participation framework (i.e., expected actions and intended goals) helped guide my analysis of the language used to frame this argumentation task. This examination was done in service of answering the following research questions:

- How did Ms. Ransom and Mr. McDonald convey the participation framework that would inform the science seminar activity?
- How does the teachers' framing during the introduction align with students' engagement during the science seminar?

This chapter is organized as case studies around each of the two classes. To contextualize the findings, for each class I first describe the progression of the lesson as well as the classroom the day of the science seminar. This description is meant to provide a clear image of how the lesson went, what the classroom physically looked like during the teacher's introduction, and how the teacher and students were arranged during this time. Then, I tease apart the participation framework that the teacher articulated: first, discussing the language used to convey *what* students should do in the argumentation task (i.e., the actions), and then the language used to express *why* students were engaging in the science seminar (i.e., the goals). I then examine relevant sociograms from the social network analysis, which offer insight into how the participation framework expressed by the teacher related to students actual engagement during the argumentation activity. Afterwards, I conclude with a summary of how the science seminar activity was framed across the two classrooms.

Case 1: Ms. Ransom's Class

Contextualizing The Science Seminar Lesson

As students entered Ms. Ransom's classroom on the day of the science seminar lesson, they picked up their science notebooks out of a bin located in the back of the room and sat down. Lab tables, which were normally placed in rows facing the front of the class, were moved to the edges of the room, and seats were arranged into two semi-concentric circles that were directed towards the whiteboard at the front of the room. Once all students were seated, Ms. Ransom welcomed them to class and asked students to complete the warm-up that was written on the board. The warm-up asked students to consider which claim they felt answered the science seminar's guiding question – When a person trains to become an athlete, how does her body change to become better at releasing energy? Students independently worked on the warm-up while the teacher circulated the classroom and answered questions. After a few minutes, Ms. Ransom called for attention and gave students a preparatory task for the seminar ("…write the claim you choose to work with during the science seminar… And then you'll wanna list any evidence that you decide you should support your claim with").

After about five minutes, Ms. Ransom provided students with time to practice reading aloud their arguments to a partner so that each had the opportunity to "hear what your claim sounds like and what your pieces of evidence sound like." The partner not speaking was told to "just listen this time though and maybe give them a point of suggestion or not." Before students had an opportunity to practice, a student asked if they would "be up there alone or with a partner" during the science seminar. This prompted Ms. Ransom to provide students with a brief description of the science seminar activity. Then, students practiced reading their arguments aloud as the teacher walked around the room and listened to a few pairs talk. Following this pair practice, the teacher assigned students to particular seats for the science seminar (i.e., who would sit in the inner semi-circle, Group 1, and outer semi-circle, Group 2, during the first round). After students re-arranged themselves in their new seats, Ms. Ransom began explaining the science seminar activity to students in more detail. During this time, the teacher stood at the front of the classroom and projected images onto the whiteboard. These images included a picture of students engaged in a science seminar, a list of student expectations, and data from one of the studies students examined prior to the lesson.

During both groups' science seminars, Ms. Ransom physically placed herself away from students, sitting on one of the lab tables located along the side of the classroom. As students engaged in the argumentation discussion the teacher took notes on a clipboard and rarely interjected. When Ms. Ransom did speak, it tended to be to inform students of the time they had left in the seminar. Using the classroom context just described as a frame of reference, I now discuss the participation framework that Ms. Ransom articulated for the science seminar activity.

Participation Framework: Student Actions During The Science Seminar

During Ms. Ransom's introduction, the teacher emphasized that students should drive the argumentation discussions. Although Ms. Ransom explained that students, and not the teacher, would be directing the science seminar activity, related exchanges between the teacher and her students suggested that students were seeking further clarification about their roles at first. For instance, the interaction in Table 5.1 took place after Ms. Ransom provided instructions for the pair practice. As seen by this exchange, the student expressed a lack of clarity as to his role during the science seminar. Both of the student's initial questions appear to map onto activities students are more familiar with: giving a class presentation ("Are we gonna be up there alone or with a partner?") or turn-taking to share ideas ("So are we gonna read one by one?"). Ms. Ransom responded by providing a general description of what the science seminar would entail ("…the people in the inner circle are gonna be the ones who start the talking. People on the outside are just gonna be doing all the listening"). In this response, the teacher explained that only the students sitting in the inner semi-circle would talk, and that all students would have the opportunity to experience that role. Ms. Ransom did not yet say what she would do during the activity.

Table 5.1: Ms. Ransom's initial description of student roles during the science seminar

Speaker	Quote
Student	Are we gonna be up there alone or with a partner?
Ms. Ransom	Ok. So, this is the tough thing. It's hard for you to get that. Ummm you'll notice that you guys, without me giving the instructions, so you notice that you guys are sitting in uh we have two sort of semi-circles set up. So, what will happen, and I'll give you more details in in a minute, is that part one of the science seminar, I'm gonna take about half of you, well, roughly half of you, put you in the inner circle the inner semi-circle, and the rest will sit on the outside. And the people in the inner circle are gonna be the ones who start the talking. People on the outside are just gonna be doing all the listening. Ummm and then halfway through, about ten minutes into it, we're gonna flip-flop. And so, the people on the outside are gonna have a chance to speak and people on the inside are gonna have a chance to just listen. Okay. Does that help you?
Student	So are we gonna read one by one?
Ms. Ransom	Ummm not necessarily. I'm just gonna let you guys start talking about [points to the whiteboard] the question.
Student	So, it's like one big group?
Ms. Ransom	Yes.

Yet, she used a passive construction to implicitly indicate that she did not intend to partake in the students' conversation ("I'm just gonna let you guys start talking about the question"). However, this message did suggest that the teacher ultimately held the power in the classroom and during this discussion. This is particularly evident in her use of the phrase "let you," which implied that students could speak to one another because they had the teacher's permission to do so.

Later on during the introduction, Ms. Ransom's language conveyed a clearer message about students directing the argumentation activity. For example, after assigning students to be in Group 1 or Group 2 Ms. Ransom explained, "During the seminar, you'll be talking to one another, not to me. Students will run the conversation. That's you guys." By adding the clause "not to me" Ms. Ransom confirmed that students would be debating the guiding question with their peers, not presenting their claims to the teacher. A few minutes later, she clarified:

> *So, you guys run the conversation. But my role is, I'm gonna start it off, just get you going, and offer prompts if needed. As much as possible, I want you to run the discussion. So, it's ok if things are quiet for a few minutes and you're just sort of sitting there, looking at each other. It's ok while you think about your ideas. It's your time to direct the conversation and share your expertise about this topic.*

Here, Ms. Ransom expressed that she wanted students to carry out the seminar and make the argumentation discussion their own, and that she would interject only if necessary.

Ms. Ransom continued to communicate this message throughout the introduction to the science seminar. The teacher rarely spoke throughout her students' seminars; indeed, her contribution at the beginning of Group 1's discussion served to redirect a student who engaged in a more traditional teacher-student dynamic (see Table 5.2).

Table 5.2: Reminder by Ms. Ransom of seminar being student led

Speaker	Quote
Student	[Turns away from classmates and faces the teacher] Can I just do it?
Ms. Ransom	Yup. You guys are in charge.
Student	[Reads from notebook] Athletes can create more mitochondria in their body to release more energy. Oh yeah, [faces the teacher] can I do the evidence?
Ms. Ransom	[Gestures toward other students with hand] Please. It's up to you.

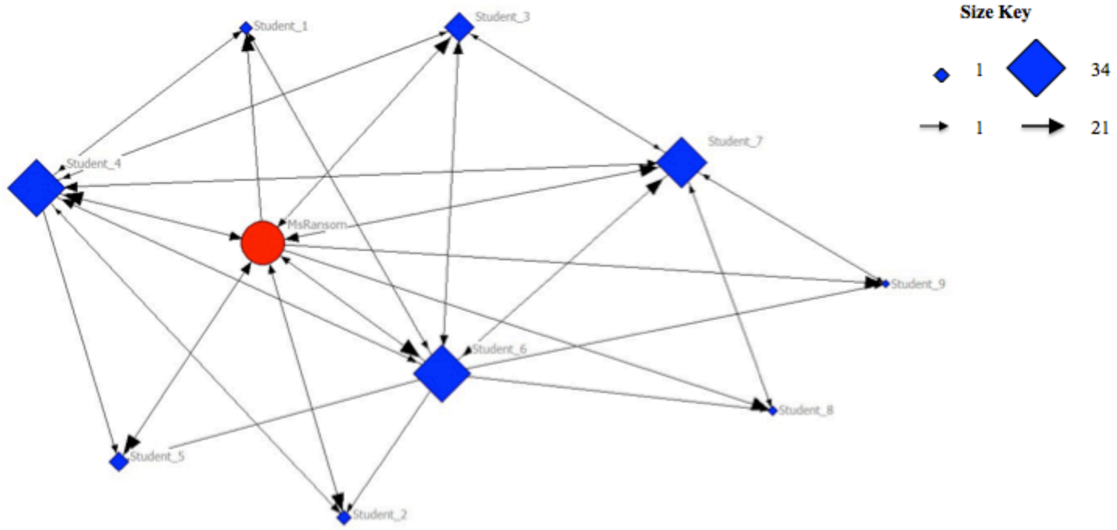
The interaction in Table 5.2 captures this student's uncertainty with his role as he shared his claim about how training changes an athlete's body to get better at releasing energy.

Although this transcript demonstrates the tension some students experienced taking ownership of the seminar, Ms. Ransom's language and gestures illustrate how she reminded students that they need not turn to her for guidance or approval ("you guys are in charge" and "It's up to you").

Despite some students' initial struggle with driving the science seminar, both of the argumentation discussions in Ms. Ransom's class comprised mostly of student talk. Specifically, student utterances made up 83.9% of Group 1 and 90.8% of Group 2's science seminars. As seen through the sociograms in Figure 5.1, all students engaged in the science seminar activity to some extent either by talking and/or by being talked to during the argumentation discussion. For Group 1 the smallest student node (the blue diamonds) was sized as one, which means all students contributed at least one utterance during the science seminar. During Group 2's seminar, there were a few students (Students 6 and 7) who did not verbally participate, although remarks were directed at them. Additionally, as indicated by the variation in node size, there appeared to be certain students who dominated the argumentation discussion in both groups (e.g., Students 3, 4, 5 and 7 in Group 1, and Students 3, 4, 5, 8, 9 and 10 in Group 2).

When comparing Ms. Ransom's node (the red circle) in both sociograms, it becomes evident that the teacher did speak more during Group 1's seminar (26 utterances) than during Group 2's seminar (16 utterances). However, many of these instances were similar in nature to the example shown in Table 5.2 in which the students looked to the teacher for permission to participate. It is also important to note that, although students did direct many comments to their peers both sociograms indicate that students spoke to the teacher as well.

Group 1



Group 2

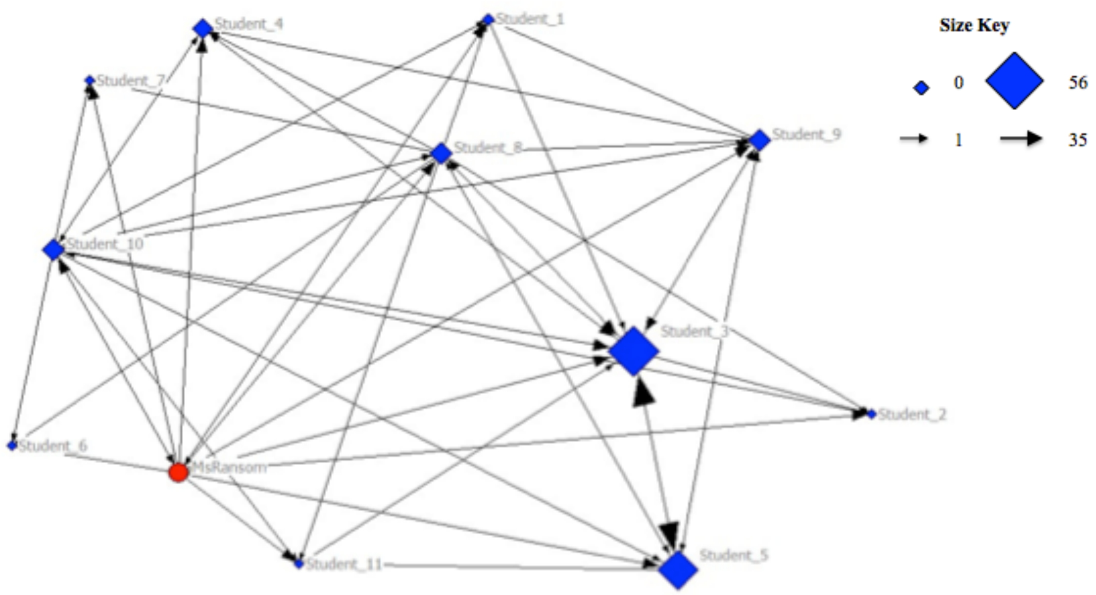


Figure 5.1: Sociograms of general participation in Ms. Ransom's class

This may capture the tension students initially felt driving the argumentation discussion and directing conversation to other students, instead of to the teacher. Also, the fewer ties to the teacher during Group 2's seminar may be a reflection of these students having had the opportunity to see and learn from their peers in Group 1 as they engaged in the argumentation activity.

Participation Framework: Goals For The Science Seminar

There were a few instances during the introduction to the science seminar in which Ms. Ransom explained *why* students were engaging in the argumentation discussion. When she touched upon this idea, the teacher focused on the ways that interactions during the seminar could improve students' understanding of the topic being debated. For instance, while introducing the activity she explained, "The purpose of the science seminar is to use everyone's knowledge to come to a deeper understanding of something." A few moments later, Ms. Ransom added, "During a science seminar you have a chance to learn something new and change or build on your own ideas by listening to what others have to say." The teacher's explanation encouraged students to pay attention to their peers' comments during the discussion, and described that doing so would result in their learning from each other. Ms. Ransom later repeated this sentiment when she said, "The goal here is to work together to better understand possible answers to this [science seminar's guiding] question". While Ms. Ransom noted that student interactions could support learning, her language tended to focus on the evolution of each student's individual understanding of the topic being debated (i.e., "your *own* ideas"), as opposed to a general understanding shared by all members of the class.

Ms. Ransom reiterated this individualistic goal a few minutes later, when a student asked about the ways that they could respond to their peers' ideas (see Table 5.3). Ms. Ransom's response shows that she supported students adding onto, and evaluating, their classmates' arguments. Yet, the reason the teacher urged them doing so was that these types of interactions would enable each student to improve their own argument (i.e., "…bring in new ideas, review, adapt, and change what *your* thoughts are.").

Table 5.3: Ms. Ransom reiterating individual understanding

Speaker	Quote
Student	Ummm well, if we're not in the same group as like ummm like someone who makes a point, I'm listening and they're talking, like the next time when we come in are we allowed to like add on to their point or like go against it?
Ms. Ransom	Absolutely.
Student	Okay.
Ms. Ransom	That's the whole point of doing this, is to bring in new ideas, review, adapt, and change what your thoughts are. This is a moving system here. It's not stationary. What you have written on the paper is not, you know, you're not gonna get a stamp on it. This is ummm you're adapting right now.

Figure 5.2 summarizes how Ms. Ransom framed the goal for the science seminar. The side of Figure 5.2 labeled "The actions" captures how each student was expected to bring his or her own idea into the debate to share and discuss with others; the various shapes represent students' different ideas. The altered shapes on side of Figure 5.2 labeled "the intended goals" illustrates how each student's individual ideas were to be adjusted and revised based on what they had learned from others during the discussion. Ms. Ransom encouraged interactions amongst students, noting that "everyone's knowledge" would enable students to develop a "deeper understanding" of the topic being debated, which is illustrated by the arrows connecting students' ideas. However, Ms. Ransom's emphasis was on each student's individual understanding. For example, she said, "…you have a chance to learn something new and change or build on your *own* ideas" and "That's the whole point of doing this, is to bring in new ideas, review, adapt, and change what *your* thoughts are". Thus, the activity was framed as supportive of individual learning; a particular student's understanding could be altered as a result of an interaction during the science seminar. Moreover, because the teacher's language stressed that students would take up different ideas from these interactions (that would

subsequently impact their initial thinking), there are multiple final ideas possible on "The Intended Goals" side of the figure.

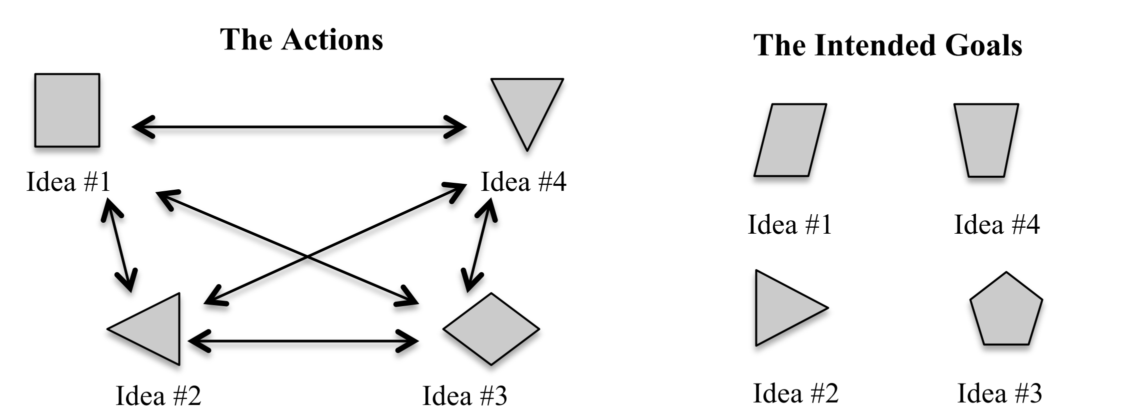


Figure 5.2: Individual understanding emphasized in Ms. Ransom's classroom

The data thus indicate that Ms. Ransom used language to frame a particular goal for students during the science seminar: *interact with peers to learn new ideas, which might possibly result in revisions to their original arguments.* I now turn to describing Mr. McDonald's framing of the science seminar activity; although similar to Ms. Ransom's regarding the actions students were expected to engage in, Mr. McDonald's was different in terms of the goals for the argumentation activity. As I discuss in the Summary section, there is alignment between these varying goals, and the different ways students in these classrooms partook in the science seminar.

Case 2: Mr. McDonald's Class

Contextualizing The Science Seminar Lesson

As the bell rang, signaling the beginning of class, students entered Mr. McDonald's classroom and took a seat. Without direction from the teacher, students sat down in chairs that were arranged into two semi-concentric circles and opened up their science notebooks. The seating arrangement for the science seminar faced the whiteboard at the front of the room, and the lab tables (where students typically worked) were moved to one side of the classroom. Two sign language interpreters (SLI) that translated for three students who were deaf or hard of hearing sat down near the science seminar arrangement – one at the front of the classroom near the whiteboard, and the other at the back of the room. As the class started, Mr. McDonald requested that students move "into the inner or the outer circle" and clarified that the initial seating was not final, as "you'll get a chance to be in the inner circle and in the outer circle." Once students rearranged themselves, Mr. McDonald explained that they would be "discussing the following question today…when a person trains to become an athlete, how does the body change to become better at releasing energy?"

Before getting into any details of what students would be doing during the seminar, Mr. McDonald asked if "anybody had an experience like this where you've been in a seminar and you've been kinda sitting in an arrangement like this?" Three students replied, mentioning, "it was not exactly a seminar, but it was like this fishbowl discussion;" "I've been at a conference table;" and "last year, in Social Studies, we did an argument thing with all the class." The teacher repeated each student's contributions after they shared, and then related those experiences to a science seminar. The teacher then directed students to complete the warm-up activity, explaining that they would "have some time to write down some notes for ourselves that we wanna bring up during the actual seminar portion." Specifically, he asked students to "look back at page forty-six, at the claims you came up with based on the studies" in order to "figure out which claim you would like to umm present today." Students worked independently on the warm-up while the teacher worked individually with a student who had been absent the previous day, so that she would be prepared to participate.

After a few minutes, Mr. McDonald brought the class back together and began discussing the goals for the science seminar activity. He acknowledged that this particular argumentation activity might be a new experience for students, and thus he was "not gonna start you in a whole group," but instead would first have students "share ideas with a partner." Before the partner practice, Mr. McDonald gave students about six minutes to engage in a preparatory task. He said, "Take a look at the claim you came up with yesterday, you can refer back to the study you read, and write down your claim again, and then you wanna write down some evidence." Then students engaged in the pair practice; as students talked to a peer, the teacher circulated the classroom attending to student questions. Following the pair practice, the teacher transitioned to the science seminar, explaining the logistics for the argumentation task ("how things are going to happen in class today"). As Mr. McDonald described the science seminar, he projected a few images onto the whiteboard including a list of student expectations and a picture of students carrying out a science seminar. The teacher also pointed to and read aloud sentence starters he had written out on a poster, which he said students could reference "if you don't know how to enter the conversation."

During both groups' argumentation discussions, the teacher sat at the back of the classroom, took notes on a clipboard, and spoke only to inform students of the time remaining in the seminar. With this classroom context in mind, I now turn to how Mr. McDonald framed the participation framework for the science seminar, starting first with the student actions he articulated and then moving onto the goals for the activity.

Participation framework – Student Actions During The Science Seminar

Throughout the introduction to the science seminar, the action Mr. McDonald emphasized was that students should drive the discussion. For instance, preceding the science seminar Mr. McDonald often used language to indicate to students that they would be carrying out the argumentation activity, and that he would not be involved. For instance, he explained that the science seminar would allow students to "learn a little more from each other without the interference of well me really." He expanded on this idea, saying:

> *My role today is gonna be pretty limited. You are responsible for running this discussion, you're responsible for the exchange of ideas, you're responsible for your own learning today.*

Here, Mr. McDonald expressed how students would be in charge of conducting the science seminar ("you are responsible for running this discussion") and that the teacher's part would be small ("My role today is gonna be pretty limited."). Furthermore, his repeated use of the phrase "you are responsible" continued to place emphasis on students' roles during this activity.

Mr. McDonald also acknowledged that this type of argumentation task was different for students, especially in terms of their driving it. For example, he said "it's probably gonna feel a little weird, not having someone directing you what to do with what to say and when to say it". Such language called attention to the distinction between this science seminar activity, and previous experiences students might have had in science classes. During the introduction, a few students demonstrated uneasiness with this amount of responsibility (see Table 5.4). As illustrated in this excerpt, in making sense of how the seminar would run, students mapped the argumentation discussion onto activities with which they were more familiar.

Table 5.4: Mr. McDonald stressing a student-driven discussion

Speaker	Quote
Student 1	When you're discussing with like your group or like the inner circle and the outer circle, umm will there be like raising hands and like talking or –
Mr. McDonald	So, that's up to you. I'm not running the show.
Student 2	Ummm how are we just gonna decide who goes? Who gets to talk first and like go after?"
Mr. McDonald	You're running the show. Number One, the number one expectation today, you are running the conversation. You're running the conversation. I'm not running the conversation. I'm not picking on people to respond to questions. It is solely up to you as the inner circle.

For instance, Student 1's question ("will there be like raising hands and like talking") aligns with the expectations of a traditional initiate-response-evaluate (IRE) conversation, in which students take turns speaking and only do so when given permission by someone with more authority, which is usually the teacher. Even after Mr. McDonald continued to articulate the non-traditional role he intended to take ("So, that's up to you. I'm not running the show."), and students kept conveying discomfort ("Ummm how are we just gonna decide who goes? Who gets to talk first and like go after?"), the teacher persisted to express and place responsibility for the discussion on students (e.g., "you're running the show," "I'm not running the conversation. I'm not picking on people to respond to question").

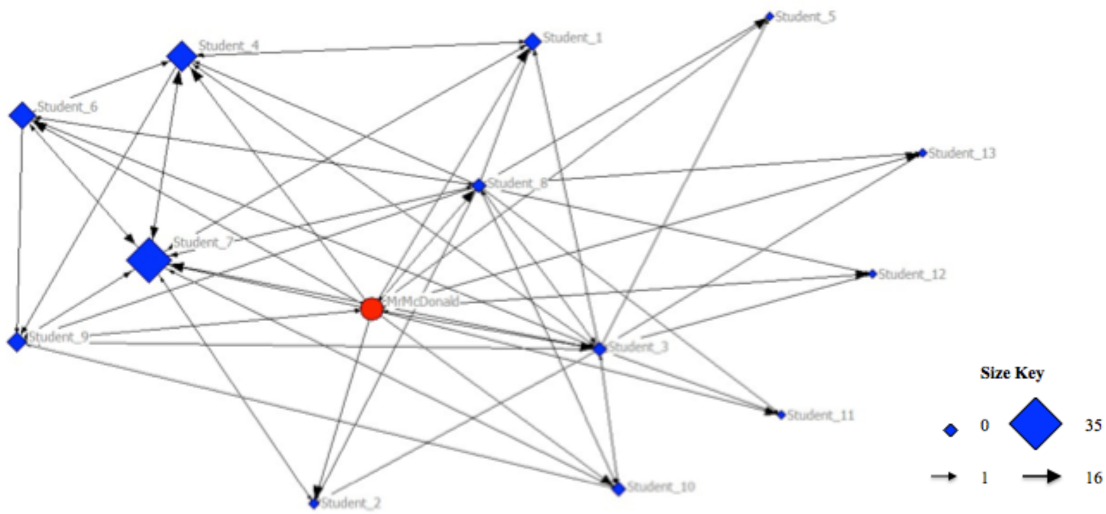
Furthermore, Mr. McDonald touched on how this particular argumentation activity would enable students to engage in a discussion with peers. For example, he later said "I'm expecting that you respond to one another. This is an opportunity to have a conversation, not go around in the circle and just state claims. It's a real conversation". The teacher thus used language to push back on a seminar encompassing typical turn-taking interactions. Throughout the introduction, Mr. McDonald continued using language both to liken the science seminar to an organic discussion amongst peers, and to acknowledge that students might feel odd taking the reins. For example, just before Group 1 started their seminar, the teacher mentioned, "It might be a little rough at the beginning, but once you get into it, feel free to have that free-flowing conversation." At other times, the teacher mentioned his limited role in the seminar, but let students know that if necessary he would interject to guide them. "If you get stuck in the conversation, that's okay," Mr. McDonald told the class, explaining that students would not engage in this task without the necessary supports:

> *That's what I'm here for. I might do a little prompting to say, "Hey, we're a little off topic right now. Let's get back on the train tracks." But otherwise, I'm pretty much going to be out of your hair today.*

Similar to earlier in the introduction, Mr. McDonald's language took an informal tone as he removed himself from the activity (e.g., "…without the interference of well me really" and "I'm pretty much going to be out of your hair today"). Such language moves served to place the teacher on equal footing with students, further enabling them to drive the science seminar.

Despite the hesitancy some students expressed carrying out the science seminar activity, both of the argumentation discussions in Mr. McDonald's class included mostly student talk (see sociograms in Figure 5.3). Specifically, student utterances made up 88.1% of Group 1 and 88.5% of Group 2's science seminars. Across both groups, all students engaged in the science seminar in some capacity; either they talked to a peer, or another classroom member directed a remark at them.

Group 1



Group 2

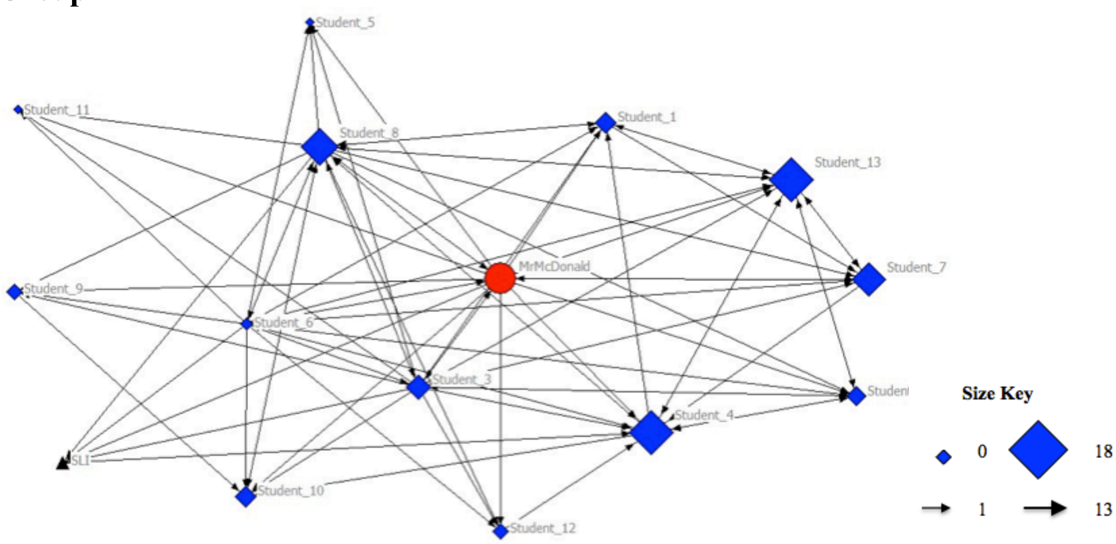


Figure 5.3: Sociograms of general participation in Mr. McDonald's class

More individual students spoke during Group 1's seminar than during Group 2's seminar. This is evidenced by the largest student node including 35 utterances for the first discussion, compared to 18 utterances for the second discussion (see Size Key in Figure

5.3). Node size also indicates that across both seminars particular students participated most during the argumentation discussion (Students 4, 6, 7 and 9 in Group 1, and Students 4, 7, 8 and 13 in Group 2). The size of Mr. McDonald's node indicates that he spoke slightly more during the first seminar (16 utterances) than during the second (13 utterances). However, all of the teacher's utterances were managerial in nature (i.e., informing students how much time was left in the activity, or wrapping up the activity and bringing the class to a close). Additionally, although students did direct comments toward their peers (captured by the ties between students), they also talked to the teacher. Specifically 3 out of 13 students in Group 1 made a comment to Mr. McDonald, while 4 out of 13 students in Group 2 directed an utterance at the teacher. Similar to Ms. Ransom's class, this may have been a result of the initial discomfort students felt driving the argumentation discussion.

Participation Framework: Goals For The Science Seminar

Throughout the introduction to the science seminar, there were a few moments during which Mr. McDonald explained to students the purpose of engaging in this particular argumentation activity. When the teacher framed the goals for the seminar, he emphasized how the classroom members' joint understanding would be improved as a result of students working together and discussing the question (When a person trains to become an athlete, how does her body get better at releasing energy?). For example, prior to the pair practice Mr. McDonald said, "The goal for today really, and really the goal for any science seminar, is to share information with each other uh that's gonna help us deepen our understanding of a particular question that we're talking about." In this explanation, the teacher touched upon the ways that interactions amongst students could support the group's learning ("…share information with each other uh that's gonna help us deepen our understanding"). Mr. McDonald's use of the phrase "our understanding" specified that it was the class's communal learning that would be enhanced.

On multiple occasions during the introduction, the teacher reiterated this communal goal, emphasizing that the best way to achieve it was by students listening to their peers. For instance, he articulated that students ought to:

> *… be sharing some ideas with each other, uh some thoughts you had after reading some of those studies yesterday, some thoughts you have uh regarding some of the other evidence we've collected using the sim, and any other observations you've made throughout the unit to really kinda deepen our understanding.*

Here, Mr. McDonald clarified the various data sources that students could bring into the discussion. Implied here was that, since students had analyzed different studies prior to the day of the science seminar lesson (see Appendix A for the data from these studies), each student would contribute ideas and perspectives with which others were unfamiliar. This aligns with the language the teacher used to highlight student actions during the science seminar, especially in terms of the activity being student-driven, which would subsequently support their learning (e.g., "You are responsible for running this discussion, you're responsible for the exchange of ideas").

Up to the point in which Group 1 commenced their discussion, Mr. McDonald continued to convey the goal of the seminar as students working together to develop a stronger and shared understanding of the scientific phenomenon being debated. For example, right before the start of the science seminar, the teacher reminded students of the following:

> *Our big goal today, work together to better understand possible answers to the question…That's our goal for today. We wanna increase our understanding of this question, we wanna deepen our understanding, we wanna learn from each other about this question.*

As illustrated by this excerpt, Mr. McDonald repeated the need for students to interact with their peers in order to improve the class's understanding of how athletic training changes a person's body. Again, the teacher used the phrase "our understanding," highlighting the ways that each student's engagement in the science seminar would lead to the group developing a more nuanced, collective comprehension of the topic of interest.

Figure 5.4 represents the goal for the science seminar that Mr. McDonald expressed throughout the introduction to the activity. Like Figure 5.2 (described in Ms. Ransom's case study), this figure also involves the actions and goals of the science seminar since both aspects inform the purpose of students carrying out the argumentation discussion. The side of Figure 5.4 labeled "The Actions" illustrates how the teacher emphasized the expectation of each student bringing in their own ideas of how the body changes with athletic training (e.g., "…evidence we've collected using the sim, and any other observations you've made throughout the unit…"), which they would share with peers during the seminar. This aspect of the goal is reflected in the different colored shapes being distributed amongst individuals. Yet, Mr. McDonald stressed that the reason students ought to engage in the science seminar was that it could improve everyone's communal understanding of the discussion topic (i.e., "*our* understanding of the question"). The side of Figure 5.4 labeled "The Intended Goals" represents this communal understanding, showing all classroom members developing one all-encompassing idea of the scientific phenomenon being debated that was built from everyone's contributions, but is also new in itself.

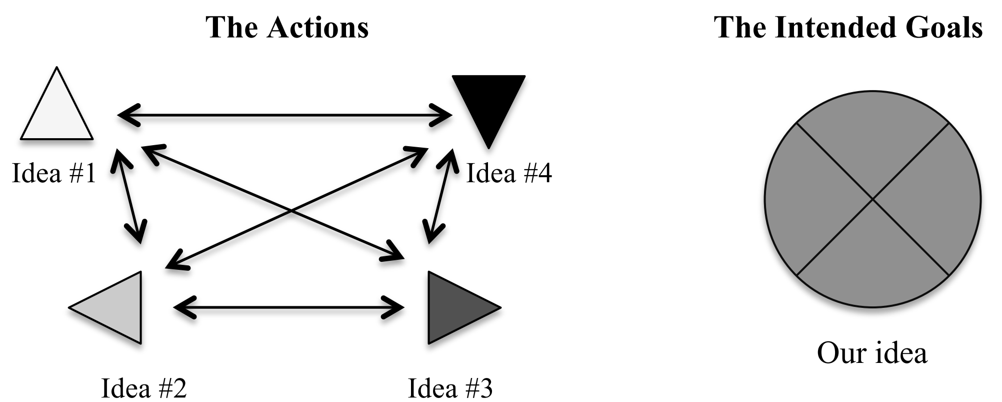


Figure 5.4: Communal understanding emphasized in Mr. McDonald's classroom

Moreover, although not explicitly stated, Mr. McDonald's framing implied that students' original arguments would change as a result of their interactions with other students that held other ideas.

Mr. McDonald conveyed a particular goal for students when participating in the science seminar – *interact with peers to share ideas, which results in the whole class developing a stronger, shared understanding of the scientific phenomenon*. In the following section I discuss the similarities and differences between the two teachers' framing of the participation framework for the science seminar activity.

Summary

In this chapter I explored the ways by which Ms. Ransom and Mr. McDonald's language during the introduction to the science seminar framed particular participation frameworks for this argumentation activity. As seen in Table 5.5 below, both teachers expected their students to interact with their peers while driving the science seminar. Demonstrated by the sociograms presented thus far, the ways students across both classrooms engaged in the activity aligned with this expectation. However, although both Ms. Ransom and Mr. McDonald promoted social interactions between students, the teachers gave different reasons for students to do so.

Table 5.5: Participation framework articulated by teachers during the introduction

	Student actions during the science seminar	Goals for the science seminar
Ms. Ransom	• Student driven discussion	• Individual construction and revision of argument
Mr. McDonald	• Student driven discussion	• Communal construction and revision of argument

Ms. Ransom explained that through these interactions, students could learn from their peers, which could result in each *individual* student revising their original argument. While Mr. McDonald also expressed that the seminar would result in revisions to students' initial ideas, he articulated that by working with peers and sharing ideas, classroom members would develop a *communal* understanding. Thus, the teachers described different goals for the seminar. This difference is interesting to consider when examining the sociograms for building that emerged from these classrooms argumentation discussions (see Figure 5.5).

In both classrooms, students built on other's ideas during the science seminar activity. Specifically in Ms. Ransom's class, 27.7% of Group 1 and 10.3% of Group 2's utterances included students recognizing some aspect of a previous contribution and utilizing it to further the discussion. Conversely, 62.7% of Group 1 and 62.8% of Group 2's utterances in Mr. McDonald's class were identified as "Building". Examining the sociograms for building in Figure 5.5 offers more insight into which individuals were engaged in this aspect of argumentation, and whose ideas they were adding onto.

The sociograms from Mr. McDonald's seminars show how his students built off more peers' ideas (as seen by the number of ties between students) in comparison to the sociograms from Ms. Ransom's seminars. Although a few students in Ms. Ransom's Group 1 also made numerous building ties, these were off comments made by three students (i.e., Students 4, 6 and 7). Students in Mr. McDonald's seminars however, built off the ideas of more students (i.e., namely, Students 1, 3, 4, 7, 8 and 9 in Group 1, and Students 1, 2, 3, 4, 7, 8, 10 and 13 in Group 2). Furthermore, by analyzing the size of nodes in the sociograms (see Size Keys in Figure 5.5), it becomes clear that more students in Mr. McDonald's class often engaged in this type of dialogic interaction. It is important to keep in mind the amount that each discussion was coded as "Building" (see percentages in previous paragraph), otherwise the patterns of the sociograms might give off the impression that the science seminars across these classrooms were very similar (e.g., Ms. Ransom's Group 1 and Mr. McDonald's Group 2), when they were not.

The manner by which students in these classes partook in the science seminar, especially in terms of interactions in which they built off each other's ideas, aligned with the goals the teachers emphasized. For instance, Ms. Ransom's framing of the goal highlighted the importance of students developing a stronger individual argument, informed by what they learned during this particular activity.

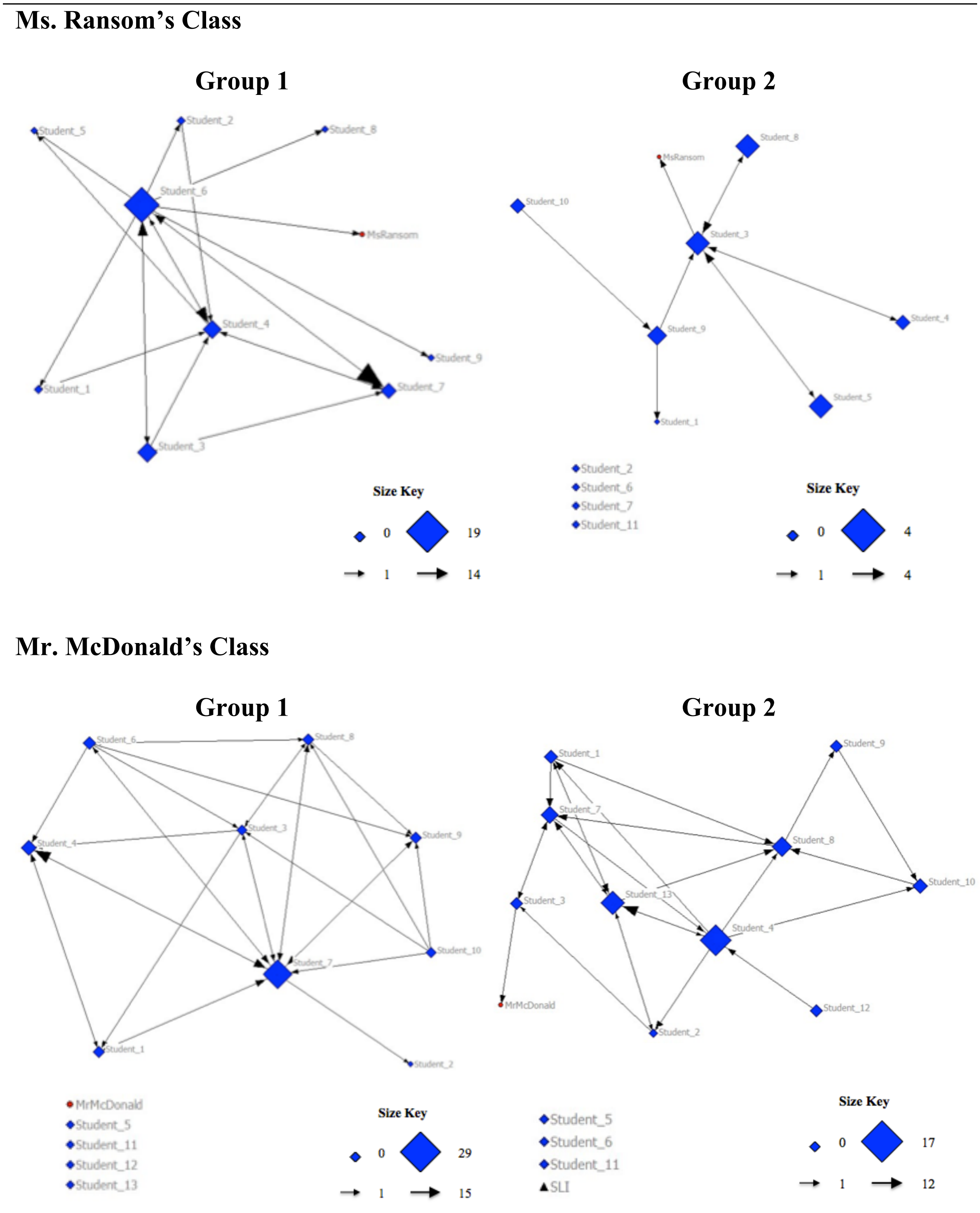


Figure 5.5: Sociograms of building across both classrooms

However, Mr. McDonald's framing stressed a communal understanding. As illustrated in Figure 5.5, Mr. McDonald's articulation focused on students working to bring together different ideas, a purpose that would have more strongly encouraged students building off each other. Although both teachers were successful in supporting students in dialogic interactions, the articulated underlying goal for scientific argumentation was different. Consequently, there was variation in the types of student dialogic interactions, specifically in terms of students building on each other's ideas.

Chapter 6 – Examinations of Teacher and Student Interactional Moves Around Critique

The sociograms from the social network analysis (SNA) of the three classrooms' science seminars highlighted various interactional patterns across the structural and dialogic components of argumentation. One pattern of particular interest was the manner in which classroom members engaged in critique during the argumentation discussions. In three groups' seminars (Ms. Ransom Group 2, Ms. Allen Group 1, and Ms. Allen Group 2), there were high instances of students critiquing arguments made by their peers. Consequently, I analyzed these groups' science seminars closely, examining the interactional patterns related to the instances during which student critique took place. Specifically, this analysis was guided by the questions:

- What are the interactional patterns around critique in the focal groups' science seminars?
- What interactional moves do the teacher and students use to mutually construct an argumentation discussion that engenders critique?

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

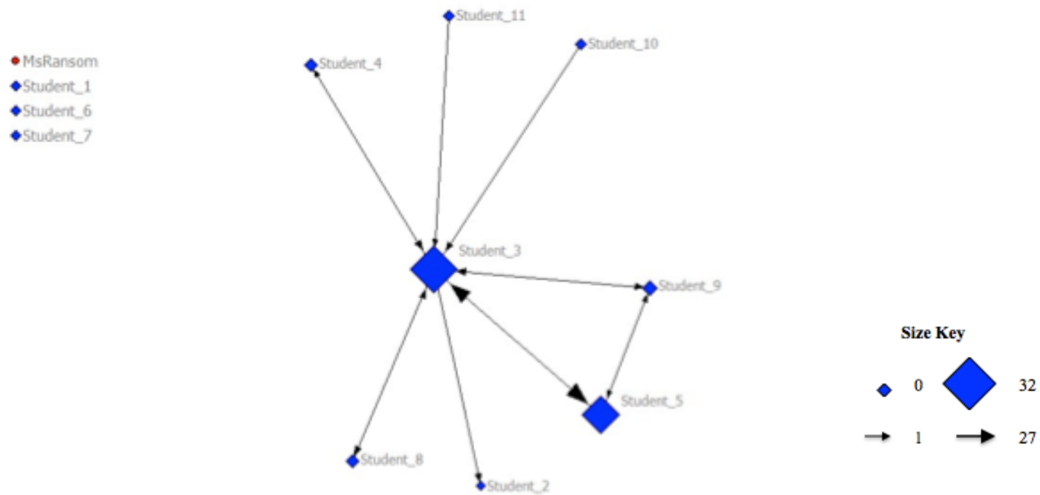
Sociograms of Critique

Throughout the three focal groups' science seminars, there were several instances of students critiquing the ideas presented by others. Specifically, the percentage of utterances coded as "Critique" was 38.4% for Ms. Ransom's Group 2, 29.7% for Ms. Allen's Group 1, and 21.9% for Ms. Allen's Group 2. See Table 3.7 for information and examples about how utterances of critique were coded across the argumentation discussions.

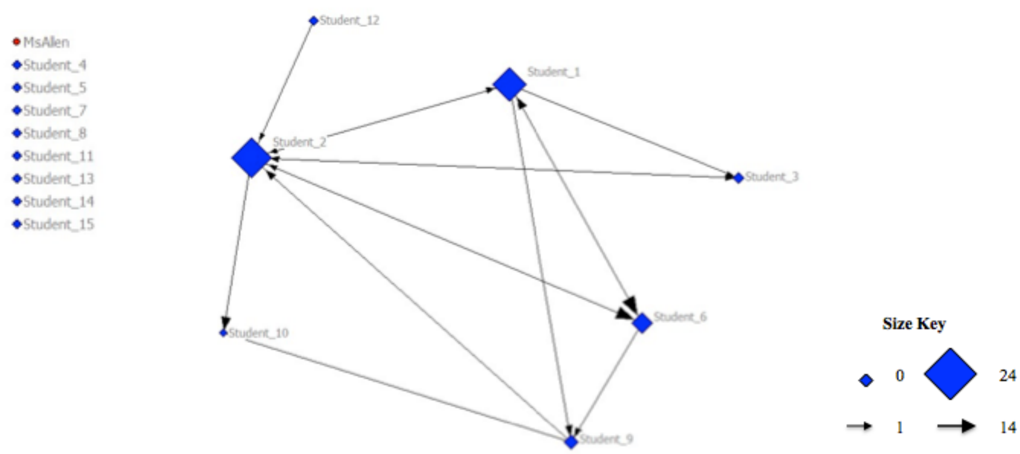
The sociograms in Figure 6.1 illustrate the interactional patterns around critique in the groups' seminars. Note that there were individuals in all of these groups who did not make an utterance containing critique, nor were they the recipients of such an utterance; these isolated actors are listed to the left of each sociogram. In Ms. Ransom's class, these isolated individuals included 4 out of 12 people (33%) in the group. A larger percentage of classroom members in Ms. Allen's class did not partake in critique – 9 out of 15 (60%) from Group 1, and 8 out of 14 (57%) from Group 2. Across both classrooms, Ms. Ransom and Ms. Allen's names are included in these lists, meaning the teachers did not evaluate nor dispute any student's contribution during the science seminar. However, as described later in this chapter, this is not to say the teachers were uninvolved in creating circumstances that enabled and stimulated critique during the discussions.

Across the three seminars, a few classroom members are prominent in terms of producing critique, evidenced by the larger size of their nodes.

Ms. Ransom Group 2



Ms. Allen Group 1



Ms. Allen Group 2

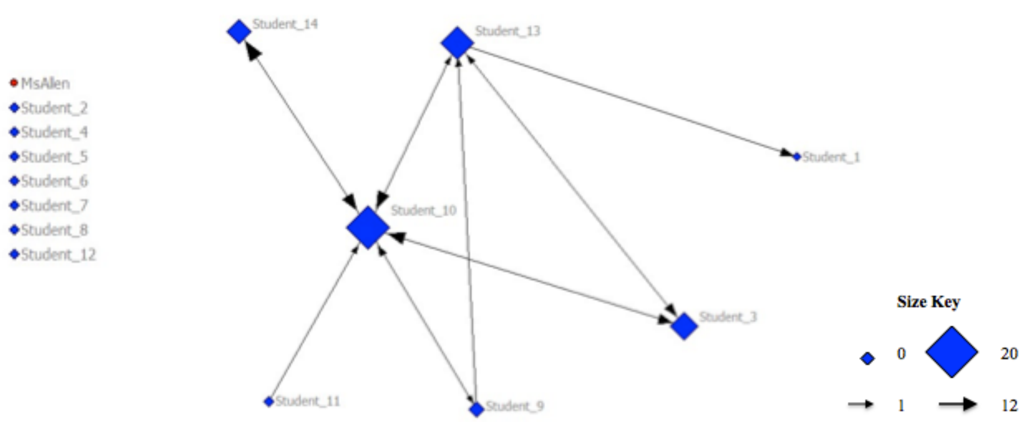


Figure 6.1: Sociograms of critique in the focal seminars

Specifically, these individuals include Students 3 and 5 from Ms. Ransom's Group 2 (with 32 and 24 utterances), Students 2, 1 and 6 from Ms. Allen's Group 1 (with 24, 19 and 10 utterances respectively), and from Ms. Allen's Group 2, Students 10, 13, 3 and 14 (having made 20, 14, 11, and 9 critiquing utterances, in that order). Relatedly, the ties in the sociograms (i.e., the arrows between the actors) offer insight into not only who produced critiquing ties, but also who was the recipient of them. In all three seminars there was one individual who not only critiqued often, but also frequently received critique from various other students. These individuals were Student 3 in Ms. Ransom's Group 2, Student 2 in Ms. Allen's Group 1, and Student 10 in Ms. Allen's Group 2.

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

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

Interactional Moves Around Critique

In this section I describe the findings from the discourse analysis, which focused on identifying and examining the interactional moves that stimulated critique during the focal groups' science seminars. Though across the focal classrooms both the teacher and students made moves that stimulated critique, the types of moves they made differed (see Table 6.1). The analysis revealed that these moves served various functions, all of which created circumstances that prompted students to engage in critique with their peers.

Table 6.1: Interactional moves that engendered critique

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

I now present and discuss these interactional moves and their functions, illustrating each through excerpts from the various seminars. While the transcription conventions used to conduct and represent the discourse analysis are described in Chapter 3, it is worth noting that the bolded words in the excerpts correspond to utterances previously coded as "Critique" (see full coding schemes in Appendices C and D for details). It is helpful to know where the critiquing utterances occurred in order to understand how they were engendered by particular interactional moves.

Interactional Moves Made by the Teacher

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

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

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

The following excerpt is from Group 1's science seminar. In Line 5, Ms. Allen uses her turn to ask Student 9 to clarify his argument ("Indi- the Indian Plate will go where?"). After Student 9 does so, the teacher repeats his claim, slowing the tempo of her speech and moving her hand over a projection of the map, offering a visual representation of the student's claim (Line 7). These "contextualization cues" (Gumperz, 1992) function to highlight the ideas presented by Student 9, and to present them for further analysis. Subsequently, in Line 8, Student 6 disagrees with his peer's argument, proposing a different claim ("°**No::° isn't it North<u>west</u>**?"). Once students settle on the revised claim, Ms. Allen reiterates the new idea twice, slowing down her speech to highlight the new argument being presented (Line 12). Again this interactional move serves to allow students to think about how the new claim relates to their own, and opens up the discussion for students to dispute the new idea being proposed. Furthermore, this move helps decontextualize the claim being made from its author, which might support students in subsequently critiquing the new idea. As such, Student 14 then enters the science seminar, articulating her disagreement with the current claim (Line 14).

Excerpt 1

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

A similar sequence of events is presented in Excerpt 2, which occurred during the second group's argumentation discussion in Ms. Allen's class. In Line 3, the teacher repeats a piece of evidence that Student 10 just brought up to support her claim ("Oh in *The History of Earth*."). Then, Ms. Allen questions Student 9, placing stress on the word "you're," which emphasizes that the idea she is reiterating is Student 9's. Similar to the previous excerpt, Ms. Allen again slows the tempo of her speech, which serves to clarify the difference between different arguments ("You're saying you think it would move >faster< than fifty million? Or (.5) [slower?]"). This interactional move works to contrast

Student 10's argument with the idea presented by Student 9. In Line 4, Student 9 then disputes Student 10's idea ("[**No**.   ] **I mean like- it's slow- it would take** (.) **a** (.) **longer amount of time**"), which Ms. Allen repeats in Line 5 ("Longer than fifty million years to get there"), again placing stress on the area of contention between the students.

Excerpt 2

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

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

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

The following excerpt took place during Group 1's seminar. In Line 2, Ms. Allen uses her turn to prompt students to react to Student 2's argument ("Okay (.5) now next person to say I >agree< or I >disagree< because?"). The manner in which the teacher frames her question during this turn not only encourages students to interact with their peer, but also provides them with the language with which to do so.

Excerpt 3

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

Moreover, Ms. Allen slows her speech to focus on the two ways that students can respond, placing emphasis on the different opinions (i.e., agreement or disagreement). In Line 4, Student 9 disputes Student 2's argument, using the frame the teacher previously offered ("**I disagree because** (.) **a plate can't go over another plate without it subducting**..."). In Line 6 Ms. Allen again encourages students to respond to their peer's idea, providing the same conversational sentence starter as before ("[Anyone] wanna start off with >I agree with that because::< or I disagree?"). Not only did this bid for student contributions – specifically, contributions in which students would respond to their peers' ideas – but, by including the frame of "I disagree because," it also gave students permission to dispute those ideas, an interaction that is not common during more typical whole class discussions (e.g., IRE).

The same interactional move can be seen in Excerpt 4, which took place during the first group's seminar, about five minutes after the occurrence captured in the previous excerpt. After a few moments of silence following a student's contribution, the teacher turns to Student 6 and encourages him to respond to Student 2, who had just disagreed with his argument (Line 3).

Excerpt 4

1	Student 2:	**It's been going Northeast the whole time and making like a collision zone** (.5) **I- I mean Student 6 says it's <all of a sudden> gonna be a transform or something** (.) **it's gone collision this whole time** (.) **why would it change now**?
2	(3.5)	
3	Ms. Allen:	((looking at Student 6)) Do you have anything to say?
4	Student 6:	°I think we have a disagreement here°
5	Ms. Allen:	((looking at Student 6)) Do you might- do you >agree or disagree<?
6	Student 6:	Well:: (1.5) it's always been going up (.) so sometimes it could happen (1.5) like it might go down (.) it might to up. Sometimes

		we don’t know what happens but (.) I usually agree
7	Student 3:	Student 2 then Student 1
8	Student 2:	**It’s been like** (.) **I don’t see how it would change now**. [**That’s-**]
9	Student 1:	[Umm yeah] it’s been going up and it will probably go up **but** (.5) **what do you mean >it’s gonna go down**?< **It’s been going up for the past like five hundred- six hundred million years what makes you think it’s gonna go down so like in fifty million years**?

Attending to Student 6’s apparent discomfort with the situation, evidenced by his whispered speech (“°I think we have a disagreement here°”), Ms. Allen then articulates two potential avenues Student 6 can take in his response (“Do you might- do you >agree or disagree<?”). This interactional move functioned to remind students that conventions for the science seminar activity allowed them to contest their peers’ arguments. In Line 6, Student 6 answers his peer’s question, appealing to agreement, although his response indicates that he continues to believe a different claim is viable. However, two other students then more openly articulate their dissent (e.g., in Line 8 Student 2 says, “**It’s been like** (.) **I don’t see how it would change now**”).

Although Ms. Allen was predominantly observed enacting this interactional move, there were also a few instances during which the “discussion leader” also performed this move. The discussion leader was a student appointed by the teacher to direct the conversation, who was responsible for calling on students to speak during the seminar. An example of such an instance can be seen in Excerpt 1 in Line 10. Here, Student 3 employs the same language used by the teacher previously in the seminar (“°Does anybody [agree] or disagree?°”). However, unlike the teacher, Student 3 whispered this remark, possibly capturing hesitancy or discomfort in carrying out a role typically reserved for the teacher during classroom discussions. Nonetheless, it is interesting to point out how this student, who had been assigned a pseudo-teacher role during the argumentation activity, began using this interactional move, which subsequently engendered student critique. Across both of these interactional moves it is worth noting that none of Ms. Allen's comments were actually coded as critique, yet they enabled students to engage in this dialogic move. Additionally, in many of the example excerpts the teacher's slowed pace of speech served as contextualization cues (Gumperz, 1992) to highlight differences in students' arguments.

Interactional Moves Made by the Students

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

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

Excerpt 5 is from Group 2's seminar in Ms. Ransom's classroom. In this teacher's class, her students analyzed results from different studies (see Appendix A for data tables) that compared information about athletes and non-athletes (e.g., the amount of blood the heart pumps in one minute), and that they were debating the question – *When a person trains to become an athlete, how does her body change to become better at releasing energy?* In Line 4, Student 3 responds to students who had expressed why they believed the data from the studies were reliable.

Excerpt 5

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

In his response, Student 3 repeats his peers' language ("**They probably wouldn't**"); his emphasis on the word "probably" functioned to highlight an alternative possibility. Student 3 then follows this remark with, "**but** (.) **maybe the scientists want to give**

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

The “challenging statement” is also exemplified in Excerpt 6, which is from the second group’s science seminar in Ms. Allen’s class (during which students debated - *How will the Indian Plate be different in 50 million years?*). In Line 2, Student 10 responds to her peer’s argument concerning the movement of the Himalayan Mountains (“**But they’re** (.) **but they’re both** ((converging right and left hand)) **Eurasian and India**. **How will it just go like this**? ((rapidly moves hands together in air to the right))”). Student 10’s emphasis on the words “just go” and “this” functioned to make the idea of the plates moving in a particular direction (taking the Himalayan Mountains with them) sound unreasonable. The quick movement of Student 10’s hands in the air served to further point to the unlikelihood of this event and to trigger a response from her peer. Subsequently in Line 3, Student 14 disagrees, explaining why his claim is probable. After a few turns of talk, Student 3 enters the conversation. At Line 10, she too employs the “challenging statement” interactional move in her re-articulation of Student 10’s claim (“>but< I also see how Student 14 doesn’t see how that would work because India can’t just slide out and go across (.) it would [kind of have to-]”), placing stress on the words “just slide out.” Similar to Line 2, emphasizing these words functioned to position an idea (in this case, the manner by which the tectonic plates could move) as unlikely. This move consequently provoked a critiquing response from Student 10 (Line 11). Both of these examples illustrate the ways that students challenged their peers’ ideas, using language to make an opposing argument sound unreasonable and hence disputable.

Excerpt 6

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

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

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

Excerpt 7

1	(2)	((Student 3 stands up from his seat, walks to the front of the inner circle, and turns to face his peers))
2	Student 3:	((reading from notebook)) **I think Test One** (.) **Study One is a load of bogus**.
3	(1.5)	((students laugh))
4	Student 3:	Okay (1) the reason for that (1.5) <well (.) I have multiple reasons for that> (.) ((reading from notebook)) **Okay <one reason** (.) **is the data doesn't show the lifestyle of the twins and that could greatly impact the results of the test. Two** (.) **the data doesn't show whether or no the twins have medical conditions that could greatly impact the results of the test. And above all** (.) **test number one was conducted before the twins were subjected to their exercise routines** (.) **so it is invalid to examine the way an athlete's body changes because the twins hadn't become**> ((puts notebook down; finger quotes)) **athletes yet.** ((walks back to seat in inner circle))
5	Student 5:	[**I disagree with that**] **because-**
6	Student 11:	[**I disagree with that.]**
7	(4)	(…)
8	Student 5:	((facing Student 3)) **Because it says like** (.) **so what I think like this text is saying** (.) **is that like** ((checks notebook)) **the Twin A already before they conducted the test** (.) **they were already working out three hours per week** (1) **and the** ((checks notebook)) **Twin B was already having twelve hours um:: of exercise per week**. so:: I think ()
9	Student 3:	((facing Student 5)) **I don't- I don't think that's true because it**

		sa::ys that ((reading from notebook)) (.5) <**scientists tested every person in the study in the same way at the beginning of the study**> ((looks up at Student 5)) **which means before they were subjected to their exercise** [**schedules**]
10	Student 5:	[**Well**] **you exactly proved yourself wrong** ((laughs)) **because they could have just um:: done the** (.5) **three hours per week of um:: athle- of training before they start- even started the** [**test**]
11	Student 3:	[**But**] **three hours a week isn't exactly athletic**
12	Student 9:	[**It's not athletic**.]
13	Student 5:	[**Then it's doing a sport**] (.) whatever (.) same thing
14	Student 3:	**Yeah but if they're doing a sport** (.5) **they're gonna do more than three hours a** [**week**]
15	Student 4:	[**You don't**] **know that** ()
16	Student 8:	Well (.) another way wait (.) <whoa whoa whoa whoa> WAIT. Wait you have to ((looks at Student 5)) excuse you. (.5) **Because the results of the test can**- (.5) **because it says** ((reading from notebook)) **that** <**the results of the test can change depending on how hard the person tries to excel** (.) **how well they follow directions** (.) **or if they're tired**.> **So:: it's not a very reliable** [**test**]
17	Student 3:	[**And**] **there are also too many variables like** (.5) **age** (.) **well I mean** <**I guess they're all female twins**> **so:: gender no. But** (.) ((raising one finger after each point made)) **medical conditions** (.) **determination** (.) **how well they-**

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

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

Excerpt 8

1	Student 10:	I mean (.) but the Eurasian Plate (.) if it keeps on creating- (.5) if you say that it keeps on creating the Himalayas (1) **but then the other plates of the Eurasian Plate how will it <u>move</u> if it keeps on creating**? (1) It will just <u>stay</u> there in fifty million years (.) [and I believe-]
2	Student 14:	[**But like**] **the Indian Plate will eventually have to run out of land to keep on creating onto the** [**Himalayas**]
3	Student 10:	[Yeah] exactly so it if-
4	Student 14:	**It will <u>eventually</u> move** (.) **I don't think it will be in fifty years or more**
5	Student 10:	But- but it's like (.) for- it means like fif- (.5) so you're saying that in fifty million years the Himalayas will still <u>be</u> there?
6	Student 14:	[Sure]
7	Student 10:	[**But what if-] what if the Eurasian Plate decided to move**? Like (.) there's a lot of [chance-]
8	Student 14:	[I think it] (.) I think it would take the Himalayas with it because it's already on the Eurasian Plate.

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

Summary

In this chapter I described the various interactional moves that engendered instances of student critique. Although the teacher plays an important role in supporting students' engagement in argumentation discussions (Simon et al., 2006; Martin & Hand, 2009; McNeill & Pimentel, 2010), this examination highlighted the ways that both teachers *and* students can create circumstances that prompt students to critically evaluate their peers' arguments. For instance, Ms. Allen used contextualization cues (Gumperz, 1992) – such as when she clarified or repeated a student's argument, often in a slower tempo – to help students think about how their ideas related to that of their peers, and to challenge other students if they disagreed. However, students across the focal classrooms also played important roles in encouraging critique during the science seminars. For example, a few students were observed making challenging statements that served to position their peers' ideas as unreasonable, and subsequently disputable.

Furthermore, it is interesting that some of the interactional moves described in this chapter had also been previously coded as utterances of critique (i.e., bolded words in the excerpts). These moves corresponded to those carried out by students. Yet, the teacher (namely, Ms. Allen) supported students' evaluating their peers' ideas without engaging in critique herself. Thus, it appears that student critique can be engendered by language moves that encompass critique (e.g., listed points of disagreement), but that they do not have to be (e.g., clarified or repeated a student's argument). Additionally, combining the findings form the discourse analysis with the sociograms that were derived from the SNA offered rich insight into the focal groups' argumentation discussions. For instance, the students who were observed making the interactional moves that prompted critique (e.g., Student 3 from Ms. Ransom's class, and Student 10 from Ms. Allen Group 2) were also central actors in the sociograms (see Figure 6.1).

Chapter 7 – Discussion

Traditionally, science instruction has encompassed students memorizing a myriad of uncontested facts and ideas, and carrying out cookie cutter investigations that validate particular concepts, an approach that does not mirror how the discipline is carried out in real life (Osborne, 2010). Moreover, this perspective on science education has resulted in classrooms in which students primarily communicate to the teacher through initiate-response-evaluate (i.e., IRE) discourse patterns (Lemke, 1990), an interactive pattern that perpetuates the message that only the correct answer is valued during the learning process (Herrenkohl et al., 1999). In order to rectify this issue, recent reform efforts, such as the *Next Generation Science Standards* (NGSS, 2013), have reconceptualized science learning to include students making sense of the natural world through engagement in science practices (Schwarz, Passmore, & Reiser, 2017). One of the eight science practices outlined in the NGSS is argumentation, which entails students "making and supporting claims, evaluating other's ideas, and working toward reconciling their differences" (Berland, McNeill, Pelletier, & Krajcik, 2017, p. 231).

It is important for students to engage in argumentation because it plays a critical role in how scientific knowledge is constructed and revised (Driver et al., 2000). Unfortunately, research around argumentation has documented that students rarely have opportunities to engage in this science practice in classrooms. The absence of argumentation might be partly due to this science practice requiring that students, and not the teacher, lead interactions amongst classroom members (Berland, 2011). Furthermore, argumentation entails participation frameworks (Goffman, 1981) that include teacher and student expectations and goals with which classroom members are likely unfamiliar.

Thus, this dissertation study was designed to help develop a deeper understanding of various aspects of argumentation discussions (e.g., interactional patterns around questioning). Specifically, I employed a mixed methods approach to analyze video recordings of three classrooms engaged in a science seminar, a type of whole class argumentation discussion. These various analytic techniques – which included social network analysis (SNA), multiple case study methodology, and discourse analysis (DA) – resulted in rich descriptions of the focal classrooms' argumentation experiences.

The results of this dissertation study have implications for the field of argumentation in three main areas: 1) the use of sociograms to illustrate interactional patterns during classroom engagement in argumentation, 2) framing of participation frameworks for argumentation, and 3) interactional moves that engendered student critique. In this chapter, I describe the main takeaways for each of these areas and situate my findings with respect to prior research in the field of argumentation, highlighting the areas in which my dissertation offers new insight. I close with a discussion of this dissertation's limitations, and suggestions for future research.

Visualizing Interactional Patterns Through Sociograms

The sociograms of the science seminars offered visualizations of the interactions that took place during the argumentation discussions in the three focal classrooms. Specifically, these sociograms provided insight into how teachers and students engaged in argumentation across the structural and dialogic components of this science practice (e.g., which students discussed evidence amongst peers, and who were utterances of critique being directed to?). This work suggests the importance of research around argumentation integrating a focus on argument structure with dialogic interactions.

Furthermore, this dissertation points to the benefits of using multiple types of representations to capture student engagement in this science practice.

Integrating Argument Structure with Dialogic Interactions

Much prior research on argumentation has focused on the presence and quality of students' arguments in terms of certain structural parts, such as a claim, evidence and reasoning (Sampson & Clark, 2008). For instance, Sandoval and Millwood (2005) examined the manner by which high school students' substantiated claims about natural selection. Their work highlighted that students were aware of the need to include data in their arguments, but that the students often failed to include a sufficient amount of evidence to support their claims. In another study, researchers explored how different instructional scaffolds (continuous or faded) influenced middle school students' written arguments, finding that, in a posttest, students who received faded scaffolds were able to articulate stronger reasoning (McNeill et al., 2006).

Similarly, the sociograms that I created for this dissertation were also able to illustrate the structural parts of students' arguments. However, these sociograms captured how students *used* argument structure (e.g., who were students directing their claims to?), as well as which students were using it (e.g., which students discussed reasoning with other students?). This focus on the individual is different than holistic counts of a whole classes participation in argumentation. Furthermore, this type of dialogic information is useful for understanding the ways that students are, or are not, interacting amongst peers to share and discuss these structural elements, each of which play an important epistemic role in the construction of scientific knowledge.

The focus on an argument's structure can be a very productive starting point for supporting students' learning of, and engagement in, this science practice. However, to authentically partake in argumentation, students need to interact with peers to construct and revise arguments, and evaluate competing claims (Ford, 2008; 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). A number of studies have analyzed the dialogic interactions that take place as students engage in argumentation. For example, Berland and Reiser (2011) examined argumentation discussions in middle school classrooms in terms of how students persuaded peers of their claims, and how students worked together to make sense of scientific phenomenon. Recently, Manz (2016) explored how 3rd grade students constructed and critiqued knowledge about plant growth. Her study focused on students' changing use of evidence as they engaged in various investigations that pushed them to challenge and reconsider previous ideas. Sampson and colleagues (2011) developed and tested an observation protocol that can be used in real-time to capture and score the nature and quality of students' argumentation, including how students communicate and interact with peers. Although the research described examined dialogic interactions during argumentation tasks, it also highlighted the difficulty of tracking students' ideas and engagement over time. Many of these studies counted interactions across an episode of argumentation (e.g., how many times students used evidence during a particular task) or synthesized overarching trends in classroom discussions instead of examining students' individual and collective engagement across the structural and dialogic aspects of this science practice.

As I demonstrated, SNA has promise for capturing interactions between classroom members as they engage in argumentation. The various types of sociograms that I discussed in Chapter 4, each of which focused on a specific type of tie (e.g., 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 transcripts or counting the number of different instances (e.g., how many times someone critiqued). 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. Also, these sociograms allowed for comparisons – within and across classrooms – of the different groups' argumentation discussions. For instance, (although similar in the percentage of reasoning utterances during their seminars) the sociograms for reasoning from Ms. Allen and Mr. McDonald's classrooms highlighted differences between how students interacted around reasoning. Specifically, there were students in Ms. Allen's class who never offered reasoning, nor were they recipients of an utterance that included reasoning (i.e., these individuals were isolated actors to the left of the sociogram). However, in Mr. McDonald's class, all students were involved with reasoning to some degree. Furthermore, although fewer students interacted around reasoning in Ms. Allen's class, those who did, did so at higher frequencies than the students in Mr. McDonald's class. These distinctions around reasoning in these two classrooms would not have been evident only knowing the percentage of reasoning utterances during students' seminars. These representations might also be informative for teachers to better understand the argumentation occurring in their classrooms, as well as the needs of their students. For example, Ms. Allen might have benefited from recognizing that most of her students were not involved in terms of reasoning, which might prompt her to incorporate supports for students around this structural feature in future argumentation discussions.

Furthermore, the sociograms helped highlight the nature of the interactional patterns that took place as classroom members engaged in argumentation. Developing an understanding of interactional patterns that are inherent to this science practice is important since 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). 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. Yet, the sociograms I created not only showed the frequency of each classroom member's contributions (evident by the size of their nodes), but also who they were interacting with and how. An understanding of these interactional patterns can help researchers 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 "questioner" that increase their centrality in the network. As seen by the lack of questions amongst students in Ms. Allen's class (see Figure 4.9 in Chapter 4), such a strategy might have encouraged students in this classroom ask their peers questions during the science seminar.

Benefits of Using Multiple 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 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). I too employed this approach when first presenting the breakdown of the focal classes' seminars across the structural and dialogic components of argumentation (see Figures 4.2 – 4.3 in Chapter 4). This type of representation shows 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 to their critiquing?). However, like any representation, tables and graphs have limitations. One particular limitation is that they are unable to show which classroom members partook in certain aspects of argumentation, and how – something that sociograms are able to highlight.

Recently, research on argumentation has begun using sociograms derived from SNA to examine student engagement in this science practice (e.g., Yoon, 2011; Ryu & Lombardi, 2015). However, unlike prior research, this study not only looked at general participation (i.e., who spoke and who did not?), but also teased apart student engagement across argument structure and dialogic interactions. Moreover, as I demonstrated in Chapter 4, talking across multiple representations of student argumentation (i.e., sociograms and graphs) provides a richer description of each classroom's science seminars. Furthermore, developing deeper understandings of the similarities and differences across groups' argumentation discussions led to further questions and examination. For instance, noticing that three out of the six science seminars had relatively higher instances of student critique, as seen through both frequency graphs and sociograms, led to questions about what might have been occurring during those discussions to prompt this type of discursive move. Thus, not only are multiple representations helpful for developing more nuanced understandings of student argumentation, but they may also prompt ideas for future research. Additionally, capturing and making sense of students' argumentation across multiple types of representations might push researchers to expand how they conceptualize and study this science practice. For example, the visual affordances of sociograms, in combination with other forms of representation (e.g., frequency tables) might stimulate new ideas of how to operationalize the social interactions inherent to argumentation, and subsequently for more nuanced explorations of the ways that different classroom communities collectively engage in argumentation.

Participation Frameworks for Argumentation

Examining the manner by which Ms. Ransom and Mr. McDonald articulated the participation framework for the science seminar resulted in a deeper understanding of their student expectations and goals for the argumentation activity. While both teachers emphasized the importance of their students driving the conversation and interacting with peers, they highlighted different purposes for students doing so. These findings suggest the need to continue supporting teachers in developing and using rich instructional strategies to help students with the dialogic component of argumentation. Additionally, this work sheds light on the importance of how teachers frame the goals for student engagement in this science practice.

Teachers' Support for Dialogic Argumentation

Teachers play a vital role in argumentation being included in classroom instruction in part because their use of instructional strategies around this science practice impacts if and how it is integrated. For instance, the types of language supports employed by a middle school science teacher influenced her English-language learning students' successful engagement in argumentation (González-Howard, McNeill, Marco-Bujosa, Proctor, in press). In terms of dialogic interactions, this teacher was observed modeling particular language expectations to help students interact with peers during an argumentation activity. In another study, Simon and colleagues (2006) worked with a group of twelve secondary science teachers, providing them with professional development workshops around argumentation, and examining the teachers' instructional strategies for this science practice as they implemented it into their classrooms. They found that teachers with lower quality instruction offered students with narrow definitions of argumentation, definitions that focused mainly on the structural features of an argument (e.g., justifying a claim with evidence). However, the teachers whose lessons included higher quality argumentation attended to the dialogic aspects of this science practice. Specifically, these teachers recognized different positions that students could take around an argument, and highlighted the importance of counterarguments.

The dialogic aspects of argumentation require a considerable shift in instruction for teachers, which may be why some teachers continue carrying out traditional forms of discourse (e.g., IRE) even when they believe they are authentically engaging their students in this science practice (Alozie, Moje & Krajcik, 2010). For instance, in a recent study, Marco-Bujosa and colleagues (2017) found that one teacher altered argumentation activities to make them more manageable – from whole class discussion to small group work, where students eventually reported out their thinking to the teacher. Yet, the teacher did not realize that this alteration made the activity more teacher-centered, and minimized opportunities for students to speak to peers. Given the difficulties that many teachers face around the dialogic components of argumentation, it is impressive that the students in this dissertation study successfully engaged in rich social interactions with peers. The participation frameworks articulated by Ms. Ransom and Mr. McDonald may be one reason for this success.

Through various actions teachers establish how students can interact with one another during classroom tasks (Mortimer & Scott, 2003). Prior work focused on the framing of whole class discussions found that teachers often reinforce interactions in which students direct their remarks to the teacher for evaluation (e.g., Pimentel & McNeill, 2013). However, Ms. Ransom and Mr. McDonald used multiple supports for student-driven interactions, and highlighted this element in their framing of the argumentation activity. For instance, Mr. McDonald said to students, "You're running the conversation. I'm not running the conversation." Like other researchers, my findings suggest that the manner by which teachers articulate student expectations for an argumentation task impacts the extent to which students directly interact with their peers' ideas. For example, Berland and Hammer (2012) found that when a teacher repeatedly framed an argumentation discussion as including the need for students to reach consensus, students drove the activity, compared their disparate understandings of the topic, and worked towards persuading their peers of the strongest argument. Thus, it might be important for teachers to say many times, and in numerous ways, that they expect students to drive argumentation discussions. Ms. Ransom was heard articulating this idea many times; for example, at one point she said, "As much as possible, I want you to run the discussion… It's your time to direct the conversation and share your expertise about this topic." Additionally, similar to the teacher in Berland and Hammer's (2012) study, both Ms. Ransom and Mr. McDonald physically removed themselves from the argumentation activity, which provided their students with another visual reminder that the teacher would not direct the discussion.

Furthermore, Mr. McDonald openly acknowledged that the science seminar experience would be new for students and that they might feel uncomfortable at first (e.g., "It might be a little rough at the beginning, but once you get into it, feel free to have that free-flowing conversation."). Such an approach might ease students as it helps them realize that the teacher is aware of the new roles they are all being expected to take. Also, this openness from the teacher might ultimately support students in taking risks and trying new things with peers (e.g., questioning another student, or disagreeing with the interpretation of a piece of evidence). Also, Mr. McDonald's language frequently took on an informal tone when he described the science seminar task to students. For instance, at one point during the introduction he said, "I'm pretty much going to be out of your hair today." Using such a informal tone when he spoke to students likely emphasized the teacher's framing of the argumentation task as encompassing a partner participation structure (Tabak, 2002) – a type of participation structure that promotes a symmetrical relationship between the teacher and students, encouraging students to direct discussions while learning from peers.

Goals for Argumentation

Students engage in argumentation activities for particular purposes, whether they be to write persuasive arguments that explain some scientific phenomena, or engage in discussion with peers in order to learn from one another's ideas. Berland and Hammer (2012) have suggested that students' prior experiences with situations that they recognize as argumentation can be leveraged to support their learning of, and engagement in, this science practice. However, the classroom community's shared understanding of how success is defined (i.e., how they will know they achieved the goal of the argumentation task) will influence how the teacher and students engage in the science practice (Berland, 2011). It is important for the goals of argumentation to be perceived as different from those of typical science instruction so that students engage in "doing science" instead of "doing the lesson" (Jiménez-Aleixandre et al., 2000); the latter of which places authority on the teacher to direct students' learning. Research around the framing of argumentation has also described the ways that already established classroom practices influence the degree to which students take up particular goals (Berland, 2011). In other words, students may be more apt to work towards argumentation goals that align with familiar student expectations.

This study highlighted another important aspect of framing for argumentation tasks – the distinction between whether the goal is individual (one that each student should strive to achieve), or communal (whether it is a goal that the entire classroom community is working towards together). Depending on the focus of prior argumentation studies, researchers have examined both individual and communal goals with respect to students' engagement in this science practice. For instance, work around students' written arguments have explored the degree to which individual students attend to particular structural features, such as the quality of evidence (Sandoval & Millwood, 2005). However, studies focused on dialogic interactions, which tend to be in the context of an oral argumentation task, have looked into the ways that classroom communities jointly develop an understanding of scientific phenomena (e.g., Berland & Reiser, 2011). This suggests that the different foci on goals may be related to the modality in which students' argumentation is being examined (i.e., written or spoken). However, in this study, which focused on an argumentation discussion, teachers were seen articulating both goals, and students appeared to also be working towards both means.

In the case of this dissertation, both individual and communal goals resulted in the classrooms successfully engaging in this science practice, particularly in terms of students driving the discussion. However, there were differences in *how* students interacted with peers. Specifically, students in Mr. McDonald's class built on each other's ideas much more than students in Ms. Ransom's class. Recall that Mr. McDonald framed the seminar activity as encompassing a communal goal, while Ms. Ransom's language described an individual goal. The variation in how students talked to peers prompts the question – are there instances when one framing is more appropriate or productive than the other? For instance, if a teacher notices that her students are not adding onto others' arguments to further the discussion, perhaps it would be beneficial for her to frame the next argumentation task as communal, so that students are cued into building off other's ideas. This finding suggests that intentionally framing argumentation activities in particular ways (i.e., towards encompassing individual or communal goals) might be an instructional approach teachers use to support their students with particular aspects of this science practice.

Encouraging Student Critique During Argumentation

Conducting a discourse analysis of the science seminar transcripts highlighted the interactional moves that prompted students to critique their peers' arguments. Findings from this portion of my dissertation stress the relationship between discourse patterns and interactional norms (particularly in terms of what they might look like when students engage in dialogic interactions during argumentation discussions), and also suggest the need to expand our perspectives of *who* can prompt for critique during an argumentation activity.

Discourse Patterns and Interactional Norms

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

As demonstrated by the sociograms in Chapter 6, students are capable of engaging in critique. Moreover, partaking in this dialogic component of argumentation included classroom members carrying out interactional patterns that differ from those that traditionally dominate science classrooms. Across the focal groups' seminars only students were seen critically evaluating or disagreeing with their classmates; neither of the teachers were captured in these sociograms as critiquing students' ideas. This is different from IRE-style discourse in which the teacher is central to the interactional pattern (Scott et al., 2006). Thus, conditions that foster dialogic interactions amongst students during argumentation activities necessitate a shift in the role of the teacher (Schwarz, Neuman, Gil, & Ilya, 2003; Martin & Hand, 2009). For example, as discussed in Chapter 6, the teachers were critical in creating spaces during the discussions that stimulated and allowed for student critique. For instance, Ms. Ransom rarely spoke during her students' science seminars, and did not actively prompt for student critique by making any of the interactional moves that Ms. Allen did. Yet, her silence during times that students were critiquing sent the implicit message that critique was permissible and an expected action during an argumentation discussion. Consequently, her students' seminar did not include interactional patterns of students talking to and through the teacher, but instead included instances of them directly critiquing their peers' arguments.

Thus, the interactional patterns around critique conveyed an important message about the types of interactions that are valued in argumentation. As seen through the sociograms presented in Chapter 6, some students were seen speaking directly to peers and disagreeing with points brought up during the science seminar. Because the teachers did not reprimand or correct students during these instances, the message communicated to the class was that this type of behavior is expected during argumentation discussions. Furthermore, because the teachers in the focal classrooms were not observed evaluating students' ideas (a common teacher practice during IRE discussions; Mehan, 1979), students might have understood that it was on them, and not the teacher, to carry out critique. Yet, it must be noted that across the focal groups' seminars, there were students who did not partake in critique (i.e., the isolated actors to the left of each sociogram), which might be indicative of students' hesitancy and discomfort taking on such a role during classroom discussions since it is not one with which they are accustomed.

Prompting for Critique

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

As exemplified in Chapter 6, during the science seminar activity students too made particular interactional moves that prompted others to engage in critique. For instance, Student 3 in Ms. Ransom's class often articulated a challenging statement, which invited responses from his peers as he positioned certain ideas as unreasonable and consequently disputable. The findings suggest that, while we can obtain insight from teachers' instructional strategies, there is also much we can learn from observing students. Beginning to develop an understanding of what supports student critique is the first step in a process towards normalizing this type of interaction in science classrooms.

Some of this knowledge can be integrated into classroom instruction to further support students who may feel uneasy with this practice. For instance, explicitly teaching interactional moves that trigger student interactions and critique might help students slowly feel more comfortable taking on those types of behaviors (which are traditionally carried out by the teacher) during class discussions. This certainly was the case with the student discussion leader in Ms. Allen's class, as she began copying the teacher and asking students if they agreed or disagreed with a peer's idea. These strategies could help make engaging in critique an integral part of science education, which will have numerous benefits for students, including deepening their learning and increasing motivation (Ford, 2015; Henderson et al., 2015).

Limitations and Future Research

There are a few limitations from my dissertation study that are worth noting. The first limitation has to do with the study's participants. The teachers whose classrooms I examined had agreed to pilot curriculum that emphasized student engagement in argumentation. As such, these teachers were likely interested in learning to integrate this science practice into their classrooms and were willing to try new instructional strategies. Consequently, these teachers may have different beliefs and instructional practices compared to a larger sample of teachers who are not piloting an argumentation-focused curriculum. Relatedly, because of the small sample size of this work, these findings cannot be generalized (Fraenkel, Wallen & Hyun, 2012). Thus, it is important for future research to continue examining argumentation discussions in more teachers' classes – including teachers from various backgrounds who teach in a wider range of instructional contexts – to see how these experiences play out in different classrooms.

A second limitation of my dissertation has to do with the sociograms derived from the SNA of the science seminar transcripts. One limitation is that a sociogram of a particular component of argumentation, such as building off other's ideas, does not show how the focal interaction compares to other aspects of this science practice (e.g., how does students' building off their peer's ideas compare to student critique?). This is where I found combining the information from different representations and talking across these findings to be especially helpful. I recommend that future research employing sociograms to examine argumentation discourse also take advantage of the affordances of different visual representations. Another drawback of the sociograms in this study is that they are "snapshots" of each group's seminar. They do not provide information about the progression of the discussion, nor about which type of interaction might have triggered subsequent moves during the seminars. For example, was there a particular questioning tie that resulted in numerous critiquing ties amongst students? A final limitation about the sociograms in this study is that they did not capture the substance of the science content during the argumentation discussion. For instance, in the sociograms of evidence I was able to show which students were contributing evidence and how, but not what data (e.g., lung capacity, mitochondrial protein or heart test) students were using to substantiate their claims. While the focus of this work was on the interactional patterns during argumentation discussion, and not on the science content of students' arguments, it would be worthwhile for future studies to examine how particular interactions relate to the use and development of science ideas over time.

In terms of future research, I see many potential applications of SNA for work around scientific argumentation. For instance, while I highlighted the classroom members' status in the nodes (as either the teacher or a student, depending on the shape and color of the node), I could have also further examined 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 into sociograms could be of interest for researchers who want to examine the role these factors play in student engagement in argumentation. This is particularly important since studies have shown that teachers can have various expectations about students' abilities to engage in argumentation, depending on their backgrounds and schooling contexts (e.g., Katsh-Singer, McNeill, Loper, 2016). Also, like Ryu and Lombardi (2015), one could evaluate how particular students' engagement in argumentation changes over a period of time. For instance, an SNA could be conducted of argumentation discussions at various time points in the school year (e.g., fall and spring) to examine change over the school year. Another idea would be to break a single discussion up at interesting time points, such as a student bringing in a piece of evidence that resulted in the conversation shifting towards many students getting involved. This would allow for an examination of changes in who is involved and how over the course of one argumentation discussion.

Additionally, similar to Yoon's (2011) study, I could see sociograms being 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 Ms. Ransom was fairly removed from her 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. As such, future research should consider ways to use sociograms to help teachers and students see and understand their engagement in argumentation with respect to that of other classroom members.

Conclusion

Realizing the new vision of science education set forth by recent reform documents and standards is going to require purposeful work and collaboration between various educational stakeholders, including researchers, teacher educators, school administration and practitioners (NRC, 2012; NGSS, 2013). Engagement in argumentation will necessitate significant shifts in the types of interactional patterns that dominate science classrooms. To support this discursive transformation, a rich knowledge base of what discourse patterns look like when classrooms engage in argumentation is needed. In this dissertation study, I described some of the ways that SNA might be used to study interactional patterns in argumentation discussions. The visual affordances of this analytic technique offered insight into the ways that classroom members used the structural elements of an argument as they constructed, critiqued, and revised ideas about scientific phenomena.

Furthermore, students have traditionally held passive roles in science classrooms, interacting mainly with the teacher who disseminates uncontested facts (Krajcik et al., 2014). Yet, science practices, including argumentation, involve students constructing their own understandings of nature. Authentically engaging in argumentation entails students working in coordination with peers and taking on new roles (Berland, 2011), which in turn requires alteration to classroom participation frameworks (i.e., the roles and expectations of the teacher and students, as well as the goals that drive tasks; Goffman, 1981). As such, this study also sheds light on how participation frameworks for argumentation discussions were articulated by teachers during the introduction to the science seminar activity, as well as throughout the discussions by various teacher and student interactional moves (particularly in terms of moves that engendered critique). Developing a deeper understanding of these elements of argumentation will facilitate shifts in how this practice is carried out in science classrooms.

References

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., et al. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397–419.

Alozie, N. M., Moje, E. B., & Krajcik, J. S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. *Science Education*, *94*(3), 395-427.

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

Arrhenius, S. (1908). *Worlds in the making: The evolution of the universe* (H. Borns, Trans). London, England: Harper & Brothers Publishers.

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

Aud, S., Hussar, W., Kena, G., Bianco, K., Frohlich, L., Kemp, J., & Tahan, K. (2011). The Condition of Education 2011 (NCES 2011-033). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

Baker-Doyle, K. J., & Yoon, S. A. (2011). In search of practitioner-based social capital: A social network analysis tool for understanding and facilitating teacher collaboration in a US-based STEM professional development program. *Professional Development in Education*, *37*(1), 75-93.

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

Berland, L. K. & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching*, *49*(1), 68–94.

Berland L. K. & Lee, V. R. (2012). In pursuit of consensus: Disagreement and legitimizations during small-group argumentation. *International Journal of Science Education*, *34*(12), 1857-1882.

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

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

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

Borgatti, S. P., & Ofem, B. (2010). Overview: Social network theory and analysis. In A. J. Daly (Ed.). *Social Network Theory and Educational Change* (pp. 17-29). Cambridge, MA: Harvard Education Press.

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

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. National Academy Press.

Bricker, L. K. & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education, 92*, 473-498

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching*, *43*(5), 485-499.

Brown, D. (1992). Using examples to remediate misconceptions in physics: Factors influencing conceptual change. *Journal of Research in Science Teaching*, *29*(1), 17-34.

Carolan, B. V. (2014). *Social network analysis and education: Theory, methods and applications.* Thousand Oaks, CA: Sage.

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

Chin, C. & Osborne, J. (2010). Students' questions and discursive interaction: Their impact on argumentation during collaborative group discussions in science. *Journal of Research in Science Teaching*, *47*(7), 883–908.

Clark, D. B., & Sampson, V. D. (2007). Personally-seeded discussions to scaffold online argumentation. *International Journal of Science Education*, *29*(3), 253-277.

Clark, D. B., Sampson, V., Weinberger, A., & Erkens, G. (2007). Analytic frameworks for assessing dialogic argumentation in online learning environments. *Educational Psychology Review*, *19*(3), 343-374.

Collins, H. & Pinch, T. (1993). *The golem: What everyone should know about science*. Cambridge, England: Cambridge University Press.

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

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of research in science teaching*, *37*(9), 916-937.

Crawford, T. (2005). What counts as knowing: Constructing a communicative repertoire for student demonstration of knowledge in science. *Journal of Research in Science Teaching, 42*(2), 139-165.

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

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research.* Thousand Oaks, CA: Sage.

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

de Laat, M., Lally, V., Lipponen, L., & Simons, R-J. (2007). Investigating the patterns of interactions in networked learning and computer-supported collaborative learning: A role for social network analysis. *Computer-Supported Collaborative Learning, 2*(1), 87-103.

Duranti, A. (1997). *Linguistic Anthropology*. Cambridge: Cambridge University Press.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development.* New York: Teachers College Press.

Duschl, R., & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science and Education*, *22*, 2109–2139.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287-312.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades k-8.* Washington D.C.: National Academy Press.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse. *Studies in Science Education*, *38*, 39-72.

Erduran, S. (2008). Methodological foundations in the study of argumentation in science classrooms. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.). *Argumentation in science education: Perspectives from classroom-based research* (pp. 47-69). Dordrecht, The Netherlands: Springer.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science education*, *88*(6), 915-933.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*, 404-423.

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

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

Ford, M. J. & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education*, *30,* 1-32.

Fraenkel, J. R., Wallen, N. E. & Hyun, H. H. (2012). (8th Ed.) *How to design and evaluate research in education*. NY: McGraw-Hill.

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

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

Goffman, E. (1974). *Frame analysis: An essay on the organization of experience.* Cambridge, MA: Harvard University Press.

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

González-Howard, M. & McNeill, K. L. (2016). Learning in a community of practice: Factors impacting English-learning students' engagement in scientific argumentation. *Journal of Research in Science Teaching, 53*(4), 527-533.

González-Howard, M., McNeill, K. L., Marco-Bujosa, L., & Proctor, C. P (in press). "Does it answer the question or is it French fries?": An exploration of language supports for scientific argumentation. *International Journal of Science Education.*

Goodwin, M. H. (1990). *He-said-she-said: Talk as social organization among black children*. Bloomington, IN: Indiana University Press.

Greene, J. C., & Caracelli, V. J. (1997). Crafting mixed-method evaluation designs. *New Directions for Evaluation*, *74*, 19-32.

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

Haythornthwaite, C. (2002). Building social networks via computer networks: Creating and sustaining distributed learning communities. In. K. A. Renninger & W. Shumar (Eds.), *Building virtual communities: Learning and change in cyberspace* (pp.159-190). Cambridge, Cambridge University Press.

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

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences, 8*(3&4), 451 – 493.

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, *84*(6), 757-792.

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

Katsh-Singer, R., McNeill, K. L., & Loper, S. (2016). Scientific argumentation for all? Comparing teacher beliefs about argumentation in high, mid and low SES schools. *Science Education*, *100*(3), 410-436.

Katz, N., Lazer, D., Arrow, H., & Contractor, N. (2004). Network theory and small groups. *Small Group Researcher*, *35*(3), 307-332.

Kelly, G. J. (2007). Discourse in science classrooms. In S. K. Abell, & N. G. Lederman (Eds.) *Handbook of research on science education* (pp. 443-469). Mahwah, NJ: Lawrence Erlbaum.

Kelly, G. J. (2014). Discourse practices in science learning and teaching. In S. K. Abell, & N. G. Lederman (Eds.) *Handbook of research on science education (Vol. 2).* (pp. 321-336). New York, NY: Routledge.

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

Kuhn, T. E. (1962). *The structure of scientific revolutions.* Chicago, IL: University of Chicago Press.

Kuhn, L. & Reiser, B. (2006, April). *Structuring activities to foster argumentative discourse.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Landis, J. R. & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159-174.

Lantolf, J. P. (2000). *Sociocultural theory and second language learning*. Oxford, England: Oxford University Press.

Latour, B. (1980). Is it possible to reconstruct the research process?: Sociology of a brain peptide. In K.D. Knorr, R. Krohn, and R. Whitley (Eds.), The social process of scientific investigation (vol. IV). Dordrecht, The Netherlands: D. Reidel Publishing Company.

Latour, B. & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts.* Princeton, NJ: Princeton University Press.

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

Lipponen, L., Rahikainen, M., Lallimo, J., & Hakkarainen, K. (2003). Patterns of participation and discourse in elementary students' computer-supported collaborative learning. *Learning and Instruction*, *13*, 487-509.

Longino, H.E. (1990). Science as social knowledge: Values and objectivity in scientific inquiry. Princeton, NJ: Princeton University Press.

Maloney, J. & Simon, S. (2006). Mapping children's discussions of evidence in science to assess collaboration and argumentation. *International Journal of Science Education, 28*(15), 1817-1841.

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

Manz, E. (2016). Examining evidence construction as the transformation of the material world into community knowledge. *Journal of Research in Science Teaching*, *53*(7), 1113-1140.

Marco-Bujosa, L. M., McNeill, K. L., González-Howard, M., & Loper, S. (2016). An exploration of teacher learning from an educative reform-oriented science curriculum: Case studies of teacher curriculum use. *Journal of Research in Science Teaching*, *54*(2), 141-168.

Marshall, C. & Rossman, G. B. (1999). *Designing qualitative research (3rd edition).* Thousand Oaks, CA: Sage Publications, Inc.

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

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

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

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

McNeill, K. L., Katsh-Singer, R., González-Howard, M., & Loper, S. (2016). Factors impacting teachers' argumentation instruction in their science classrooms. *International Journal of Science Education, 38*(12), 2026-2046.

McNeill, K. L. & Krajcik, J. (2009). Synergy between teacher practices and curricular scaffolds to support students in using domain specific and domain general knowledge in writing arguments to explain phenomena. *Journal of the Learning Sciences, 18*(3), 416-460.

McNeill, K.L., & Krajcik, J. (2012). *Supporting grade 5-8 students in constructing explanations in science: The claim, evidence, and reasoning framework for talk and writing.* Boston, MA: Pearson.

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

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

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

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

Mercer, N. & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. London: Routledge.

Michaels, S., O' Connor, C., & Resnick, L. B. (2008). Deliberative discourse idealized and realized: Accountable talk in the classroom and in civic life. *Studies in the Philosophy of Education*, 27, 283-297.

Michaels, S, Shouse, A. W. & Schweingruber, H. A. (2008). *Ready, set, science! Putting research to work in k-8 science classrooms.* Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

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

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

National Research Council (2012). *A framework for k-12 science education: Practices, crosscutting concepts and core ideas.* Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

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

O'Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. In D. Hicks (Ed.), *Discourse, learning, and schooling* (pp. 63-103). New York: Cambridge University Press.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328,* 463-466.

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

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994-1020.

Osborne, R., & Freyberg, P. (1985). Roles for the science teacher. In *Learning in science: The implications of children's science* (pp. 91-99). Birkenhead, Auckland: Heinemann.

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* Newbury Park, CA: Sage.

Pearson, P. D., Moje, E., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other. *Science, 328*, 459-463.

Penuel, W. R., Riel, M., Krause, & Frank, K. A. (2012). Analyzing teachers' professional interactions in a school as social capital: A social network approach. *Teachers College Record, 111*(1), 124-165.

Pimentel, D. S., & McNeill, K. L. (2013). Conducting talk in secondary science classrooms: Investigating instructional moves and teachers' beliefs. *Science Education*, *97*(3), 367-394.

Pomerantz, A. (1984). Agreeing and disagreeing with assessments: Some features of preferred/dispreferred turn shapes. In J. H. Atkinson & J. Heritage (Eds.), *Structures of social action* (pp. ADD). Cambridge: Cambridge University Press.

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

Pruitt, S. L. (2014). The next generation science standards: The features and challenges. *Journal of Science Teacher Education*, *25*(2), 145-156.

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

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

Rodkin, P. C., Wilson, T., & Ahn, H. J. (2007). Social integration between African American and European American children in majority Black, majority White, and multicultural elementary classrooms. *New directions for child and adolescent development*, 118, 25-42.

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *The Journal of the Learning Sciences*, *2*(1), 61-94.

Ryu, S. (2011). *The appropriation of argumentation norms in a classroom community* (Doctoral dissertation). Retrieved from ProQuest Dissertation & Thesis Global. (3515042).

Ryu, S. & Lombardi, D. (2015). Coding classroom interactions for collective and individual engagement. *Educational Psychologist*, *50*(1), 70-83.

Ryu, S. & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, *96*(3), 488-524.

Sampson, V. (2016, April). *The importance of examining the cognitive, epistemic, and social aspects of scientific argumentation.* Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

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

Sampson, V., Enderle, P. & Walker J. (2011). The development and validation of the Assessment of Scientific Argumentation in the Classroom (ASAC) observation protocol: A tool for evaluating how students participate in scientific argumentation. In M. Kline (Ed.), *Perspectives in Scientific Argumentation: Theory, Practice and Research* (pp. 235- 264). New York, NY: Springer.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and instruction*, *23*(1), 23-55.

Sawyer, R. K. (2014). Introduction: The new science of learning. In R. K. Sawyer (Ed.). *The Cambridge handbook of the learning sciences* (2nd edition) (pp. 1-18). New York, NY: Cambridge University Press.

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

Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). Moving beyond "knowing about" science to making sense of the world. In. C. V. Schwarz, C. Passmore, & B. J. Reiser (Eds.). *Helping students make sense of the world using next generation science and engineering practices* (3-21). Arlington, VA: National Science Teachers Association.

Scott, J. (1991). *Social network analysis: A handbook.* London: Sage.

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

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

Songer, N. B. & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*, *28*(9), 761-784.

Stake, R. E. (2000). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research.* (pp. 435-454). Thousand Oaks, CA: Sage Publications.

Tabak, I . (2002). Teacher as monitor, mentor or partner: Uncovering participant structures involved in supporting student-directed inquiry. In T. Satwicz (Ed.), *Keeping learning complex: The proceedings of the Fifth International Conference of the Learning Sciences (ICLS)* (pp. 466-472). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Tabak, I. & Baumgartner, E. (2004). The teacher as partner: Exploring participant structures, symmetry, and identity work in scaffolding. *Cognition and Instruction*, *22*(4), 393-429.

Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches.* Thousand Oaks, CA: Sage.

Thorpe, M., McCormick, R., Kubiak, C., & Carmichael, P. (2007). Talk in virtual contexts: Reflecting on participation and online learning models. *Pedagogy, Culture & Society*, *15*(3), 349-366.

Toulmin, S. (1958). *The uses of argument*. Cambridge: Cambridge University Press.

Venville, G. J. & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching*, *47*(8), 952-977.

Vygotsky, L. (1986). *Thought and language* (A. Kozulin, Trans.). Cambridge, MA: MIT Press (original work published 1934).

Wasserman, S., & Faust, K. (1997). *Social network analysis: Methods and applications*. Cambridge: Cambridge University Press.

Weart, S. (2015). Climate change impacts: The growth of understanding. *Physics Today*, *68*(9), 46-52.

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

Windschitl, M. (2002). Framing Constructivism in Practice as the Negotiation of Dilemmas: An Analysis of the Conceptual, Pedagogical, Cultural, and Political Challenges Facing Teachers. *Review of Educational Research*, *72*(2), 131–175.

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

Yin, R. K. (2013). *Case study research: Design and methods.* Thousand Oaks, CA: Sage Publications.

Yoon, S. (2008). Using memes and memetic processes to explain social and conceptual influences on student understanding about complex socio-scientific issues. *Journal of Research in Science Teaching*, *45*(8), 900-921.

Yoon, S. (2011). Using social network graphs as visualization tools to influence peer selection decision-making strategies to access information about complex socioscientific issues. *Journal of the Learning Sciences, 20*(4)*,* 549-588.

Zembal-Saul, C., McNeill, K. L., & Hershberger, K. (2013). *What's your evidence?: Engaging K-5 students in constructing explanations in science*. Pearson Education.

Zohar, A. (2008). Science teacher evaluation and professional development. In S. Erduran, & M.P. Jimenez-Aleixandre (Eds.) *Argumentation in science education* (pp. 245-268). New York: Springer.

Zohar, A. & Nemet, F. (2002). Fostering students’ knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35-62.

Appendix A: Data tables for *Metabolism* unit science seminar

Study #1: How the Bodies of Identical Twins Are Different from Each Other If One of the Twins Does More Athletic Training Than the Other

Lung Test

Average Results

Twins A (normal exercise: 3 hours per week)	Lung Test (in liters)		Twins B (more exercise: 12 hours per week)	Lung Test (in liters)
Average	3.1		Average	3.8

Full Results

Twins A (normal exercise: 3 hours per week)	Lung Test (in liters)		Twins B (more exercise: 12 hours per week)	Lung Test (in liters)
Twin A1	3.1		Twin B1	4.0
Twin A2	3.2		Twin B2	3.9
Twin A3	2.9		Twin B3	3.6
Twin A4	3.3		Twin B4	3.8
Twin A5	3.0		Twin B5	3.9
Twin A6	3.3		Twin B6	4.1
Average	3.1		**Average**	3.8

Study #1: How the Bodies of Identical Twins Are Different from Each Other If One of the Twins Does More Athletic Training Than the Other

Mitochondria Test

Average Results

Twins A (normal exercise: 3 hours per week)	Mitochondrial protein (milligrams per sample)		Twins B (more exercise: 12 hours per week)	Mitochondrial protein (milligrams per sample)
Average	.04		Average	.07

Full Results

Twins A (normal exercise: 3 hours per week)	Mitochondrial protein (milligrams per sample)		Twins B (more exercise: 12 hours per week)	Mitochondrial protein (milligrams per sample)
Twin A1	.04		Twin B1	.06
Twin A2	.05		Twin B2	.05
Twin A3	.04		Twin B3	.07
Twin A4	.03		Twin B4	.08
Twin A5	.04		Twin B5	.07
Twin A6	.04		Twin B6	.09
Average	.04		**Average**	.07

Study #2: How Increased Athletic Training Changes Non-Athletes' Bodies Over Time

Heart Test

Average Results

Before the study (3 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)	**After the study** (6 months of 12 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)
Average	19	Average	22

Full Results

Before the study (3 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)	**After the study** (6 months of 12 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)
Subject #1	18	Subject #1	20
Subject #2	21	Subject #2	24
Subject #3	18	Subject #3	21
Subject #4	17	Subject #4	20
Subject #5	21	Subject #5	25
Subject #6	19	Subject #6	22
Average	19	**Average**	22

Study #2: How Increased Athletic Training Changes Non-Athletes' Bodies Over Time

Mitochondria Test

Average Results

Before the study (3 hours of exercise per week)	**Mitochondrial protein** (milligrams per sample)	**After the study** (6 months of 12 hours of exercise per week)	**Mitochondrial protein** (milligrams per sample)
Average	.04	Average	.06

Full Results

Before the study (3 hours of exercise per week)	**Mitochondrial protein** (milligrams per sample)	**After the study** (6 months of 12 hours of exercise per week)	**Mitochondrial protein** (milligrams per sample)
Subject #1	.04	Subject #1	.07
Subject #2	.06	Subject #2	.08
Subject #3	.04	Subject #3	.06
Subject #4	.05	Subject #4	.07
Subject #5	.05	Subject #5	.06
Subject #6	.03	Subject #6	.04
Average	.04	**Average**	.06

Study #3: How the Bodies of Athletes Are Different from the Bodies of Non-Athletes

Lung Test

Average Results

Non-Athletes (less than 4 hours of exercise per week)	**Lung test** (in liters)	**Athletes** (20 hours of exercise per week)	**Lung test** (in liters)
Average	5.2	Average	5.5

Full Results

Non-Athletes (less than 4 hours of exercise per week)	**Lung test** (in liters)	**Athletes** (20 hours of exercise per week)	**Lung test** (in liters)
Subject #1	4.3	Subject #1	4.7
Subject #2	4.2	Subject #2	4.4
Subject #3	5.7	Subject #3	5.2
Subject #4	5.1	Subject #4	5.9
Subject #5	5.5	Subject #5	5.9
Subject #6	5.6	Subject #6	6.2
Average	5.2	**Average**	5.5

Study #3: How the Bodies of Athletes Are Different from the Bodies of Non-Athletes

Heart Test

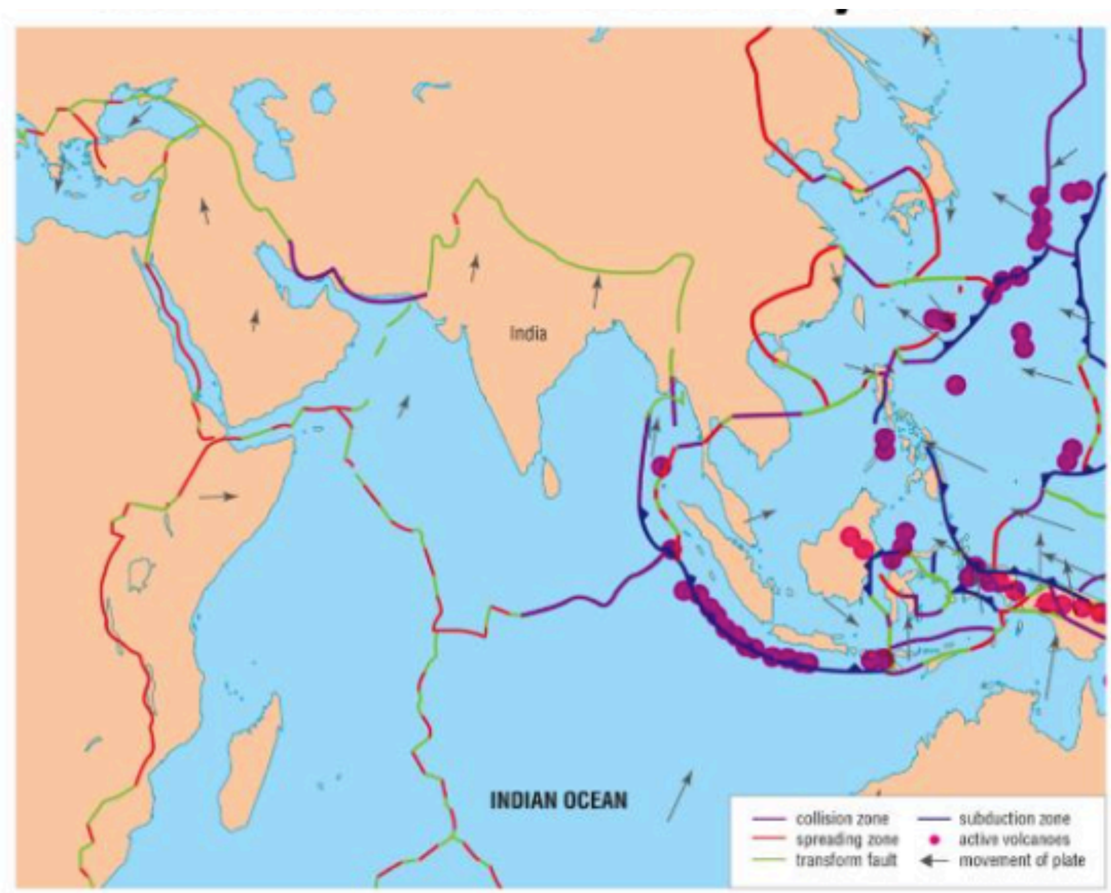
Average Results

Non-Athletes (less than 4 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)	**Athletes** (20 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)
Average	23	Average	30

Full Results

Non-Athletes (less than 4 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)	**Athletes** (20 hours of exercise per week)	**Amount of blood the heart pumps per 1 minute** (in liters)
Subject #1	23	Subject #1	32
Subject #2	22	Subject #2	28
Subject #3	25	Subject #3	32
Subject #4	20	Subject #4	27
Subject #5	24	Subject #5	29
Subject #6	24	Subject #6	32
Average	23	**Average**	30

Appendix B: Map for *Plate Tectonics* unit science seminar



Appendix C: Coding Schemes for the *Metabolism* unit science seminar

Coding Scheme for Argument Structure

Code	Description	Notes & Examples
Claim	An answer to the science seminar's guiding question.	To receive this code, students should make a clear statement that answers the guiding question. Given this science seminar's topic, the answer students provide might be simple – referencing one way a person's body changes – or complex and include multiple components (i.e. a combination of claims). Ideally, by the end of this activity students would realize that a person's body changes because of all these reasons combined. Utterances that get coded as a "claim" might include: • They are able to move more air in and out of their lungs • They can pump more blood through their heart (i.e. increased heart rate) • Their cells change by having more mitochondria. • There are many ways an athlete's body changes to become better at releasing energy, which includes being able to move more air in and out of their lungs, and pumping more blood through their heart (i.e. increased heart rate)
Evidence	Scientific data (i.e. measurements or observations that are either firsthand or secondhand) that either support or refute a claim	A reference is made to results from one of the three studies that students analyzed. This could occur as a student articulates his/her argument or when discussing specific data and/or measurements during the science seminar. Evidence might also be coded for when students ask each other a question about evidence, which might be hypothetical (e.g. "Would the type of exercise influence the twins' heart rates?") or concrete (e.g. "where the twins girls or boys?") Students may describe the study by its number (i.e. 1, 2 or 3), by who was involved in it (e.g. the study with the athletic and non-athletic twin), a combination of both (e.g. in Study #1 of the athletic and non-athletic twins), or by the results (e.g. mitochondrial levels increased after 6 months of training). Utterances can, <u>but do not have to</u>, include numerical data to get coded as evidence. When discussing evidence, student may start the utterance with "My evidence is _________", "The evidence for my

claim is ______” or “To support that claim _______”

Utterances that get coded as “evidence” might include:

- In Study 1 of the athletic and non-athletic twins, Twin B – the athletic twin – was able to move more air in and out of their lungs compared to Twin A.
    - Twin B’s average lung test was 3.8 liters, while Twin A averaged 3.1 liters on the same test.
    - All of Twin B’s lung test results were higher than Twin A’s lung test results.
- In Study 1 of the athletic and non-athletic twins, the mitochondrial protein was greater in the athletic twin.
    - The non-athletic twin had .04 milligrams per sample of mitochondrial protein, while the athletic twin had .07 milligrams per sample.
    - All of Twin B’s mitochondrial protein samples were higher than Twin A’s samples.
- Study 2, which focused on how non-athletes bodies’ change with increases in exercise, showed that training increases the amount of blood the heart pumps per minute (i.e. heart rate).
    - After 6 months of training, the person’s heart rate increased.
    - The person’s heart rate averaged 19 liters per minute before training, and then 22 liters per minute after 6 months of training.
- Study 2, which focused on how non-athletes bodies’ change with increases in exercise, showed that training increases mitochondrial protein levels
    - After 6 months of training, the person’s mitochondrial protein levels increased.
    - The person’s mitochondrial protein level averaged .04 milligrams per sample before training, and then .06 milligrams per sample after 6 months of training.
- Study 3, which focused on the difference between the bodies of non-athletes and athletes, showed that athletes can move more air in and out of their lungs (i.e. can bring in more oxygen)
    - Athletes have higher lung test results than non-athletes
    - The lung test for the athlete’s body averaged 5.5 liters, while the lung test for the non-athlete’s body averaged 5.2 liters
- Study 3, which focused on the difference between the bodies of non-athletes and athletes, showed that athletes can pump more blood through their heart (i.e. have higher heart rates)
    - Athletic bodies averaged higher amounts of blood that the heart can pump per minute (i.e.

		higher heart rates) o Non-athletes averaged 23 liters per minute on the heart test, while athletes averaged 30 liters per minute
Reasoning	An explanation of how the evidence supports the claim, which often includes science ideas	Students’ reasoning may explain how the evidence supports the claim they are making (i.e. the link) and/or the scientific principle(s) informing this connection. Reasoning could include an application of science concepts – knowledge outside of what students could perceive from the studies alone (e.g. “which helps you manage more oxygen and glucose to release more energy”). Students’ reasoning could also be an explanation of why evidence does <u>not</u> support a particular claim Utterances that get coded as “reasoning” might include: • Having more mitochondrial proteins means having more mitochondria in cells. Higher amounts of mitochondria can manage more oxygen and glucose to release more energy. • Mitochondria are the organelles where energy production occurs. • Moving more air in and out of lungs results in increases in mitochondrial proteins. • Oxygen helps the cells create more energy, so if you bring in more oxygen your cells can create more energy • Increases in the amount of blood the heart pumps per minute (i.e. heart rate) results in increases in mitochondrial proteins
Other	All other utterances not included in the three previous codes for argument structure	Utterances that get coded as “other” might include: • I thought the same thing as her. • I don’t know

Coding Scheme for Dialogic Interactions

Code	Description	Notes & Examples
Questioning	Asking about some aspect of the discussion	Given the interest of this study, utterances that are coded as questioning should be relevant to the topic being discussed. Questions that are not about the science seminar's topic would not receive this code (e.g. "When did you play soccer?"). Students can question over multiple utterances. This might also occur because their question keeps getting cut off. Students might ask each other questions about evidence or reasoning. In terms of evidence, they might ask questions in a hypothetical way (e.g. "Would the type of exercise influence the twins' heart rates?") or concrete way (e.g. "where the twins girls or boys?") Questions that are about directions related to the science seminar will not receive this code (e.g. "Can I go now?" "Do we have to raise our hands?" "Do I also say my evidence and reasoning?"). These tend to be asked to the teacher. "What?" on its own, with no utterances following it, would <u>not</u> get coded as Questioning because it is too vague Utterances that get coded as "questioning" might include: • Does training to become an athlete cause you to have more mitochondria or bigger mitochondria? • What's the evidence for your claim? • How many trials were in your study? • Other than being an athlete or not being an athlete, was everything else about the twins in your study the same? • Does it matter what the person in the study did to exercise?
Critiquing	Evaluating some aspect of the discussion, which may include feedback.	When students critique their peers' ideas they tend to start their turn with a phrase of disagreement (e.g. "I disagree"). Critiquing can be done in the form of a question. A student might critique a peer's idea, or some other aspect of the discussion (e.g. evidence). Students can critique over multiple utterances. Utterances that get coded as "critiquing" might include: • I disagree with _______. • I think the experiment where your data comes from is

		flawed. Just because they're twins doesn't mean their bodies are the same. • I don't think that's enough. You also need to consider the levels of mitochondria • That wouldn't really help unless ________.
Building on other's ideas	Recognizing some aspect of a previous contribution and utilizing it to further the discussion	When students build off of their peers' ideas they tend to start their turn with a phrase of agreement (e.g. "Yeah" or "I agree"), but not always. This is why reading the context of a response is so important. Students should be building on an idea that was previously discussed (in the same seminar). Sometimes students state "I thought the same thing" but the rest of their utterance shows that they are thinking a different idea. A student's response to a question (which could include a clarification) would get coded as Building because it captures students engaged and listening to peers. Utterances for this code may include agreement with a peer's contribution and/or additional thoughts and ideas that build off a previous contribution. Students can build on their peers' ideas over multiple utterances. Building can occur in the form of a question (e.g. "In addition to _______ and _________, is there any other evidence that supports this claim?") Do not code for Building if student's response is vague (e.g. "That would be good.") "Yeah" on its own, with no utterances following it, would not get coded as Building because it is too vague (i.e. could mean different things) Students might build on their own idea from a previous comment. However to get coded as Building, this must have been prompted by a peer's question or critique (to take into account the dialogic aspect of the interaction) Utterances that get coded as "building" might include: • I agree with _______. • I think it's a combination of both of those factors combined. • I had the same claim as him/her, but would also add that ________. • Also, it might be that __________.

		• Adding to _______’s idea I think _________. • I thought the same.
Other	All other utterances not included in the three previous codes for dialogic interactions	Utterances that get coded as “other” might include: • I don't understand the differences between the three studies • I’m not sure • When I played soccer I trained twice a week. • Do you think ballerinas are more athletic than baseball players?

Appendix D: Coding Schemes for the *Plate Tectonics* unit science seminar

* Note: If the teacher prompts students to repeat a contribution (e.g. "Could you repeat that?" or "Could you say that louder?"), code the repeated utterances in the same fashion

Coding Scheme for Argument Structure

Code	Description	Notes & Examples
Claim	An answer to the science seminar's guiding question.	To receive this code, students should make a clear statement that answers the guiding question. Given this science seminar's topic, the answer students provide might be simple – referencing one way the Indian Plate will be different – or complex and include multiple components (i.e. a combination of claims). The claims that students make will likely be related to size, location, landforms, or climate. Utterances that get coded as a "claim" might include: • The Indian Plate will move in a northeastern direction • The Indian Plate will move in a northern direction • The Indian Plate will become smaller • The Indian Plate will become bigger • The Indian Plate will move in a northern direction and become larger
Evidence	Scientific data (i.e. measurements or observations that are either firsthand or secondhand) that either support or refute a claim	A reference is made to the map that students analyzed. This could occur as a student articulates his/her argument or when discussing specific data during the science seminar. For this science seminar, students were given a map of various tectonic plates (including the Indian Plate) and information about the plate boundaries – students might reference and/or point to this map when articulating their arguments. Evidence might also be coded for when students ask each other a question about evidence, which might be hypothetical (e.g. "Would it matter if the plate movement sped up or slowed down?") or concrete (e.g. "What kind of boundary did you say was on the eastern side of the plate?") When discussing evidence, student may start the utterance with "My evidence is _________", "The evidence for my claim is ______" or "To support that claim _______" Utterances that get coded as "evidence" might include: • On the map there is a very large transform fault on the northern side of the plate.

		• The arrows show that the plate will move north. • There are only two active volcanoes on the Indian Plate.
Reasoning	An explanation of how the evidence supports the claim, which often includes science ideas	Students' reasoning may explain how the evidence supports the claim they are making (i.e. the link) and/or the scientific principle(s) informing this connection. In the context of this science seminar, Reasoning could address "What does it mean for things in the key to be happening?" This could become difficult to distinguish with Evidence when students' describe the direction that the Indian Plate might move. In the case of the arrows in the key and on the map, they mean movement in a particular direction, which is why this seems like a fizzy distinction Given the science topic being debated, students might use their hands to demonstrate what occurs at a particular plate boundary (e.g. moving their hands towards each other, moving a hand under the other, moving hands away from each other, and moving hands side by side) Reasoning could include an application of science concepts – knowledge outside of what students could perceive from the map alone (e.g. "New crust is formed when plates move apart from each other at spreading zones."). Students' reasoning could also be an explanation of why evidence does <u>not</u> support a particular claim Utterances that get coded as "reasoning" might include: • Collision zones occur when plates meet together at a convergent plate boundary • At subduction zones plates collide with each other, and because of differences in density one dives beneath the other (the denser plate goes below). • Subduction zones commonly occur where an oceanic and continental plate meet. • Oceanic plates are thicker and denser than continental plates. • Transform faults occur when plates slide past each other at a transform plate boundary. • At spreading zones plates move away from each other. • India has been moving northwest for millions of years. • If mountains are forming in that location, then the plates must be equally dense. • They'll fit into each other like puzzle pieces.
Other	All other	Utterances that get coded as "other" might include:

	utterances not included in the three previous codes for argument structure	• I thought the same thing as her. • I don't know

Coding Scheme for Dialogic Interactions

Code	Description	Notes & Examples
Questioning	Asking about some aspect of the discussion	Given the interest of this study, utterances that are coded as questioning should be relevant to the topic being discussed. Questions that are not about the science seminar's topic would not receive this code (e.g. "When did you travel to India?"). Students can question over multiple utterances. This might also occur because their question keeps getting cut off. Students might ask each other questions about evidence or reasoning. In terms of evidence, they might ask questions in a hypothetical way (e.g. "Would it matter if the plate movement sped up or slowed down?") or concrete (e.g. "What kind of boundary did you say was on the Eastern side of the plate?") In terms of reasoning they might ask how something would occur (e.g. "Why would the directions of the plates change?") Questions that are about directions related to the science seminar will not receive this code (e.g. "Can I go now?" "Do we have to raise our hands?" "Do I also say my evidence and reasoning?"). These tend to be asked to the teacher. "What?" or "Anybody else?" on its own, with no utterances following it, would <u>not</u> get coded as Questioning because it is too vague Utterances that get coded as "questioning" might include: • What's the evidence for your claim? • What was your claim again? • What happens at subduction zones? • Which of the two plates is denser? • Do you think any of the landforms will change on the plate? • What surface feature do you think will form there? • What do you think will happen near this plate boundary? • Will the size of the Indian Plate remain the same? • Does anyone disagree with me? • Does anyone agree or disagree?
Critiquing	Evaluating some aspect of the discussion, which may	When students critique their peers' ideas they tend to start their turn with a phrase of disagreement (e.g. "I disagree"). Critiquing can be done in the form of a question.

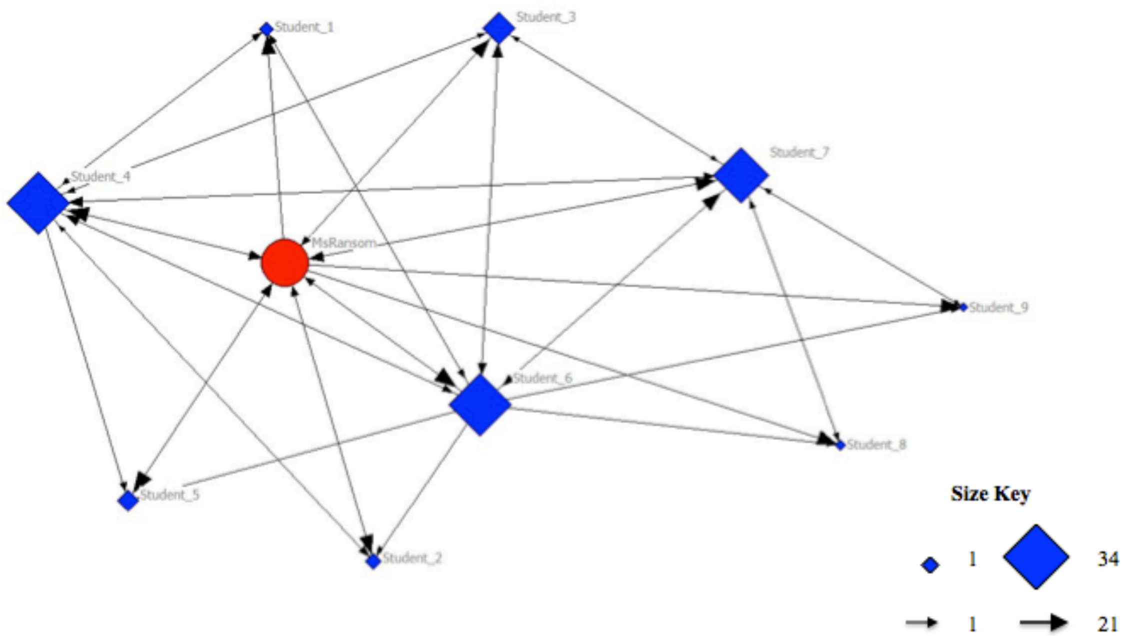
	include feedback.	Students might build off a peer’s critique as well, also in the form of critique. In this case both contributions would get coded as critique. A student might critique a peer’s idea, or some other aspect of the discussion (e.g. evidence). Students can critique over multiple utterances. Utterances that get coded as “critiquing” might include: • I disagree with _______. • I think the map where your data is coming from is flawed. • I don’t think that’s enough. You also need to consider what’s happening at the Northern boundary of the plate. • That wouldn’t really influence the size of the Indian Plate unless ________.
Building on other’s ideas	Recognizing some aspect of a previous contribution and utilizing it to further the discussion	When students build off of their peers’ ideas they tend to start their turn with a phrase of agreement (e.g. “Yeah” or “I agree”), but not always. This is why reading the context of a response is so important. Students should be building on an idea that was previously discussed (in the <u>same</u> seminar). Sometimes students state “I thought the same thing” but the rest of their utterance shows that they are thinking a different idea. A student’s response to a question (which could include a clarification) would get coded as Building because it captures students engaged and listening to peers. A teacher repeating a student’s contribution would get coded as Building because it captures a person listening to another. Often times, the teacher did so when clarifying a student’s contribution. This often included them referencing the map to point something out, or mimicking the movement at the plate boundaries Utterances for this code may include agreement with a peer’s contribution and/or additional thoughts and ideas that build off a previous contribution. Students can build on their peers’ ideas over multiple utterances. Building can occur in the form of a question (e.g. “In addition to _______ and _________, is there any other

		evidence that supports this claim?”) Do not code for Building if student’s response is vague (e.g. “That would be good.”) “Yeah” on its own, with no utterances following it, would not get coded as Building because it is too vague (i.e. could mean different things) Students might build on their own idea from a previous comment. However to get coded as Building, this must have been prompted by a peer’s question or critique (to take into account the dialogic aspect of the interaction) Utterances that get coded as “building” might include: • I agree with _______. • I think it’s both of those changes combined. • I had the same claim as him/her, but would also add that ________. • Also, it might be that __________. • Adding to _______’s idea I think _________. • I thought the same.
Other	All other utterances not included in the three previous codes for dialogic interactions	Utterances that get coded as “other” might include: • I’m not sure. • When I visited India it took us over ten hours to get there by plane.

Appendix E: All Sociograms

Sociograms of general participation in Ms. Ransom's class

Group 1



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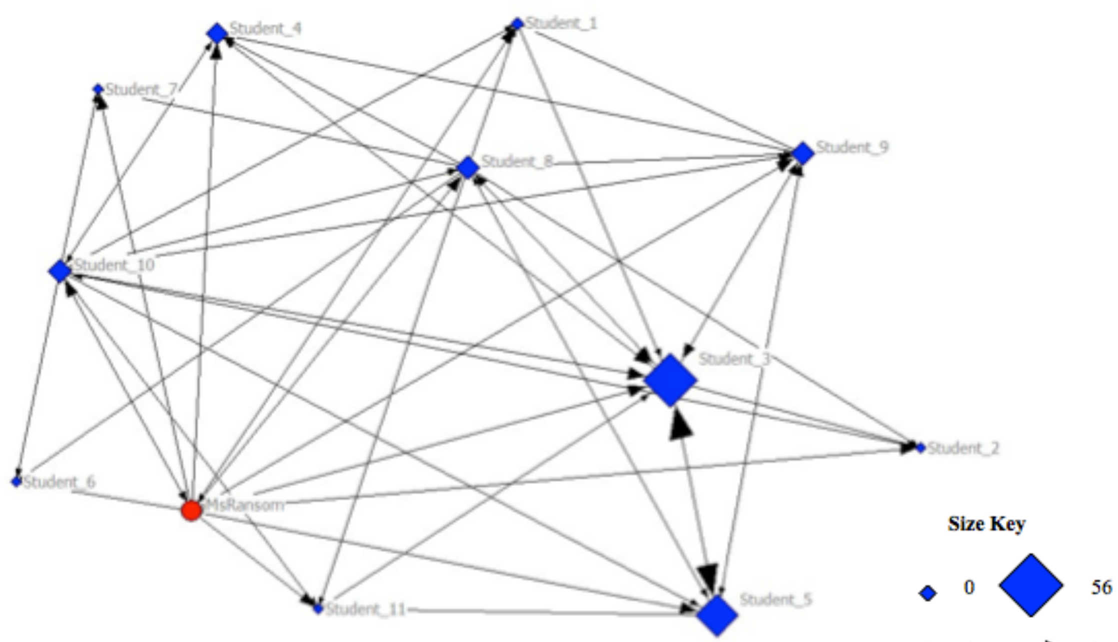
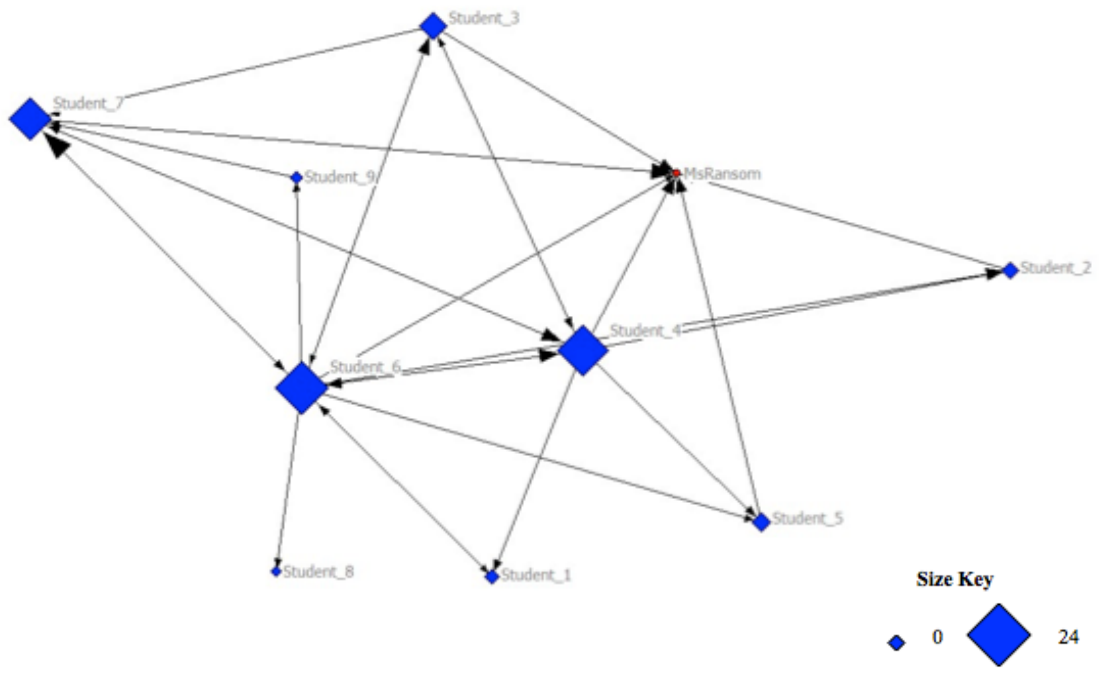


Sociograms of argument structure in Ms. Ransom's class

Group 1



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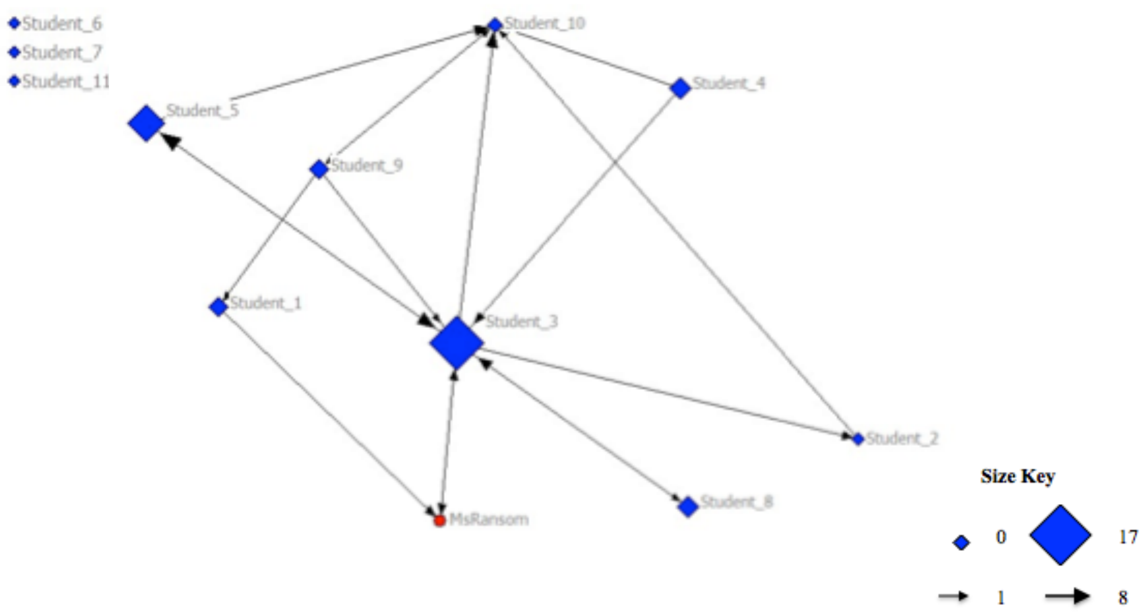
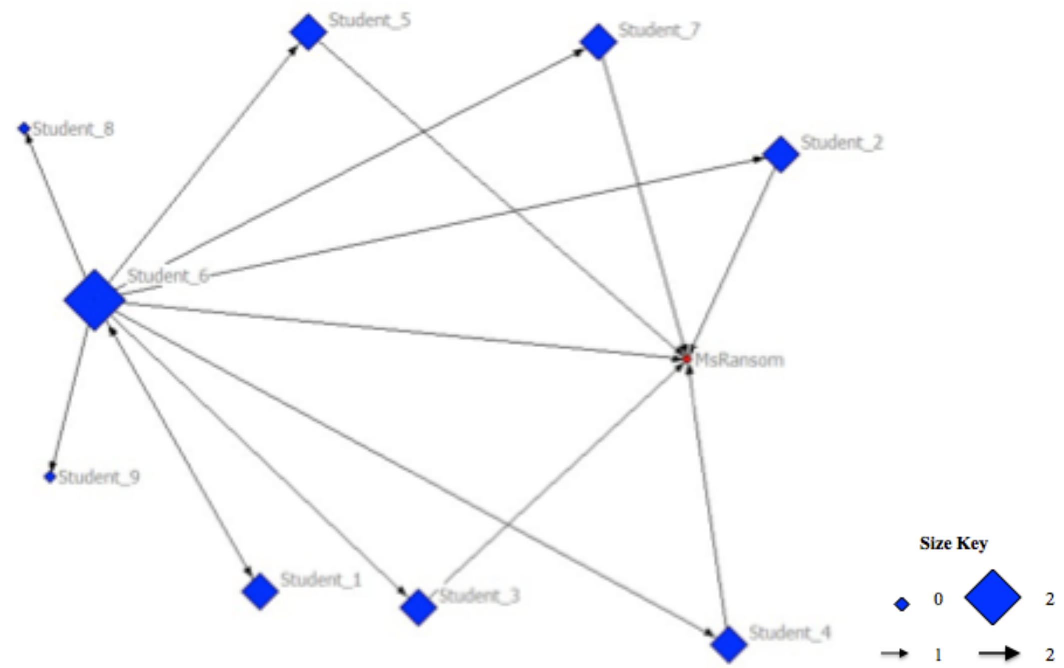


Sociograms of claim in Ms. Ransom's class

Group 1



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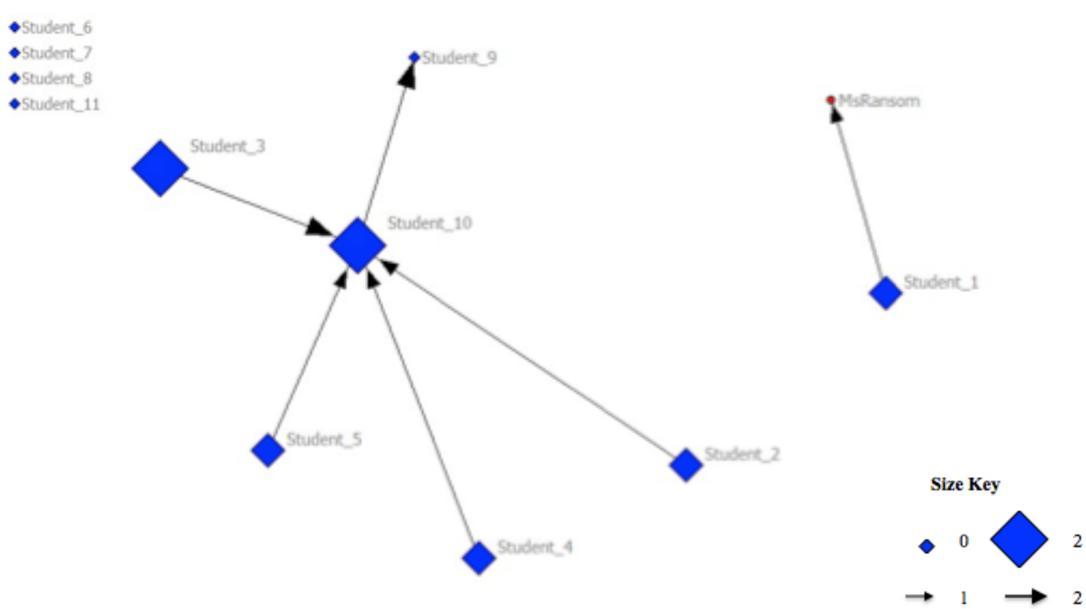
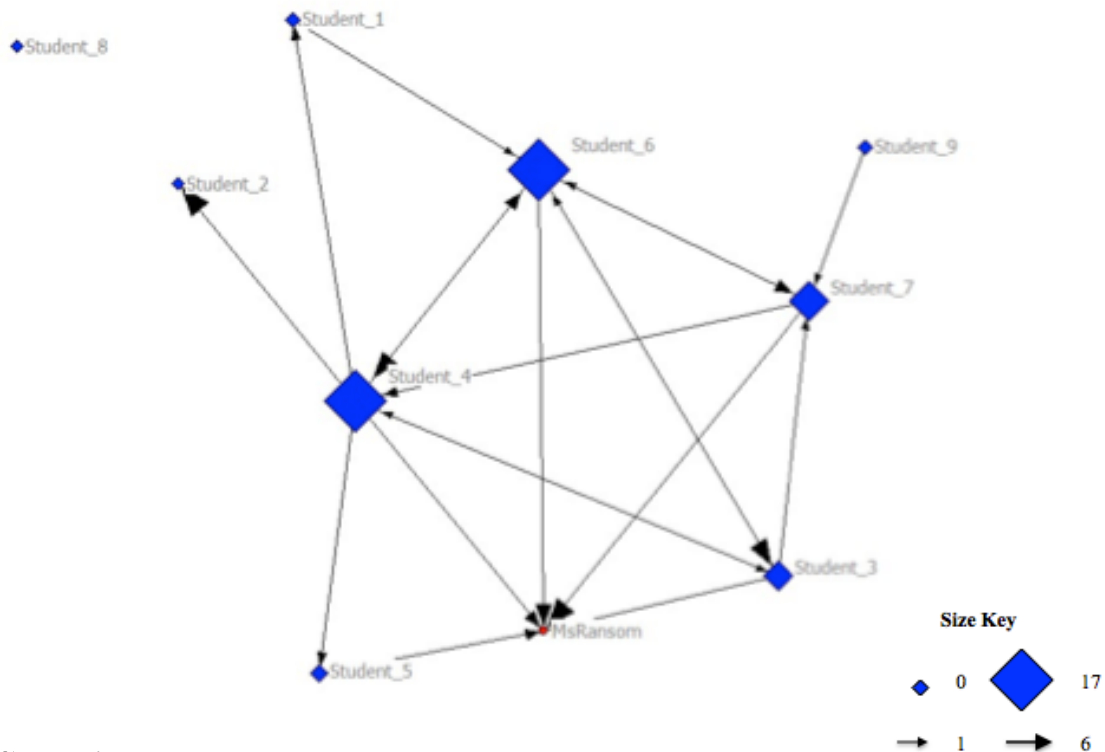


Sociograms of evidence in Ms. Ransom's class

Group 1



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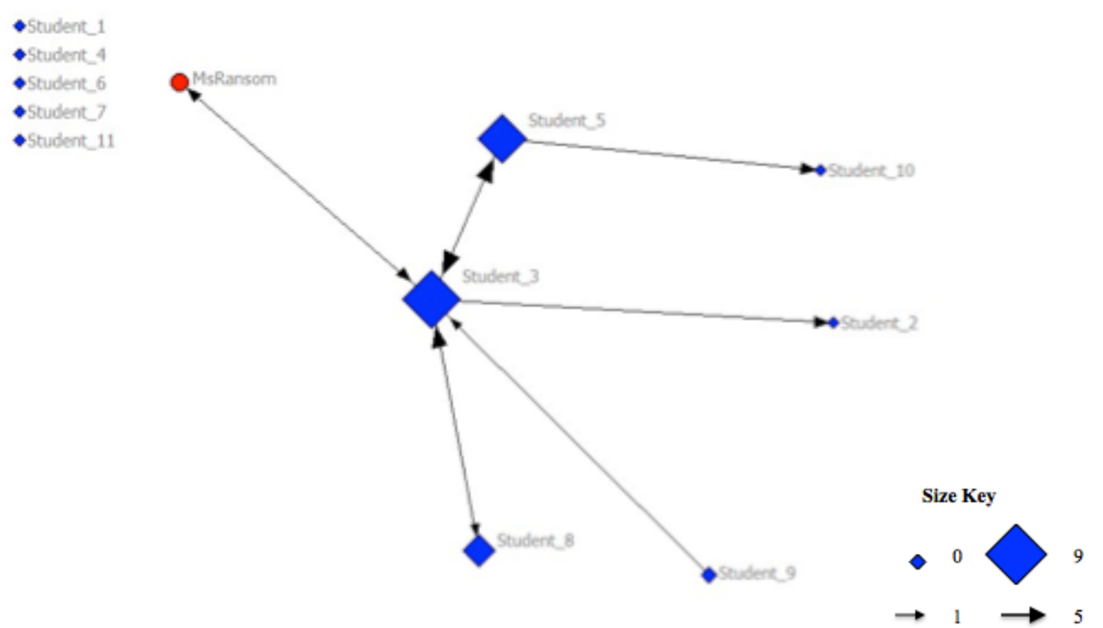

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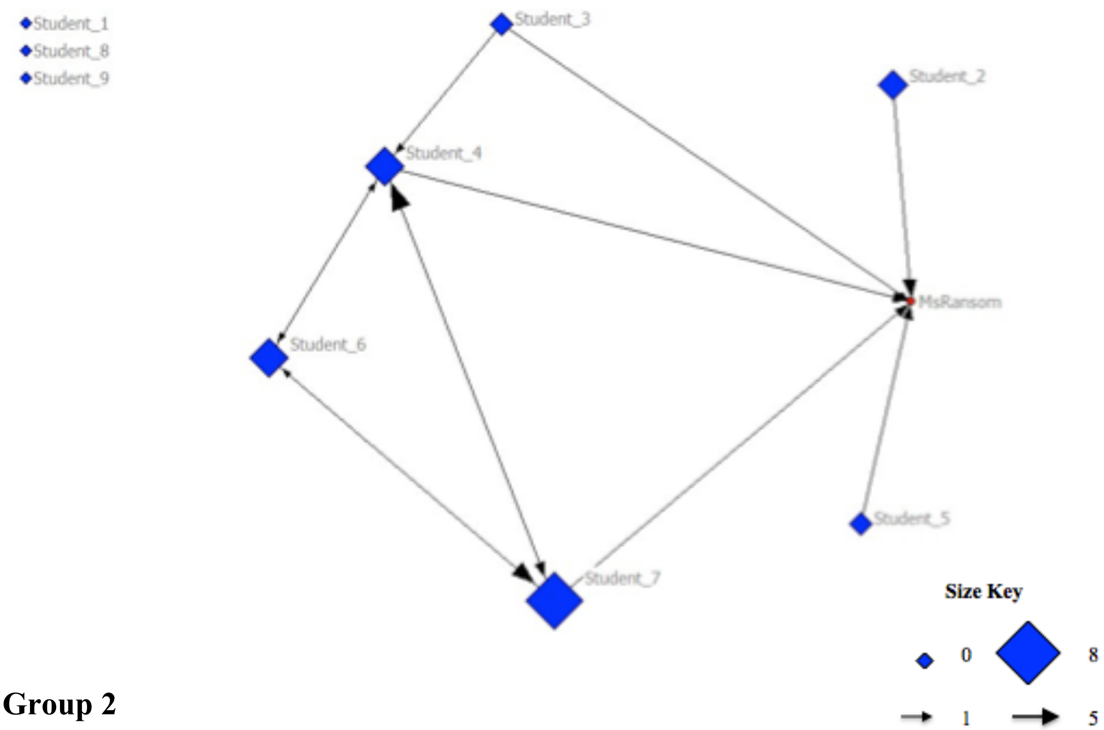

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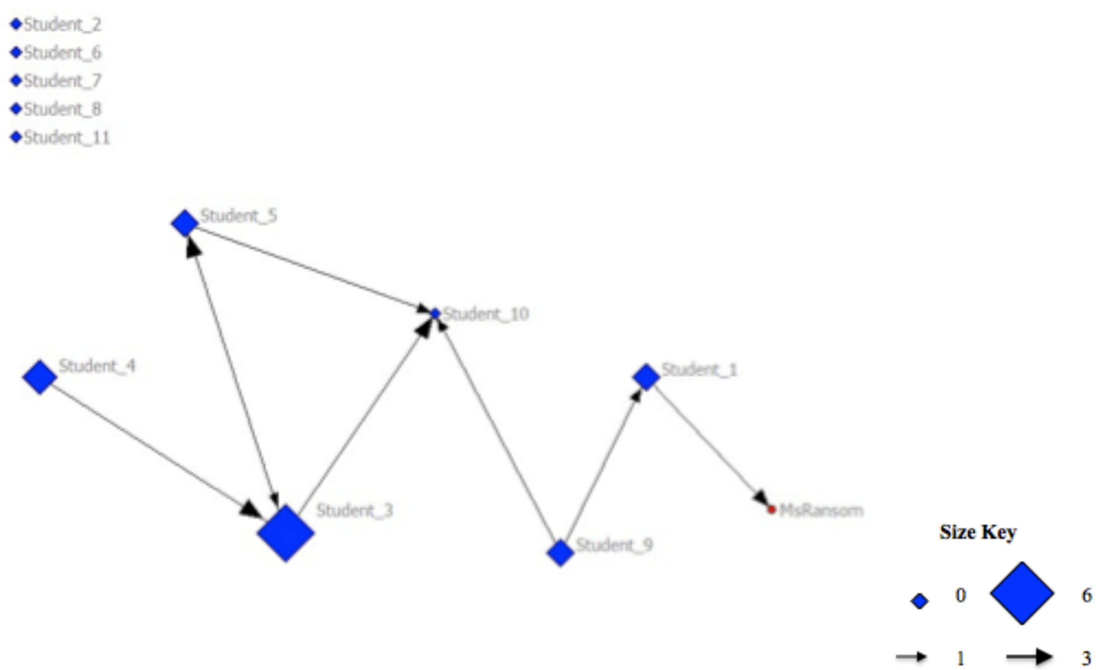
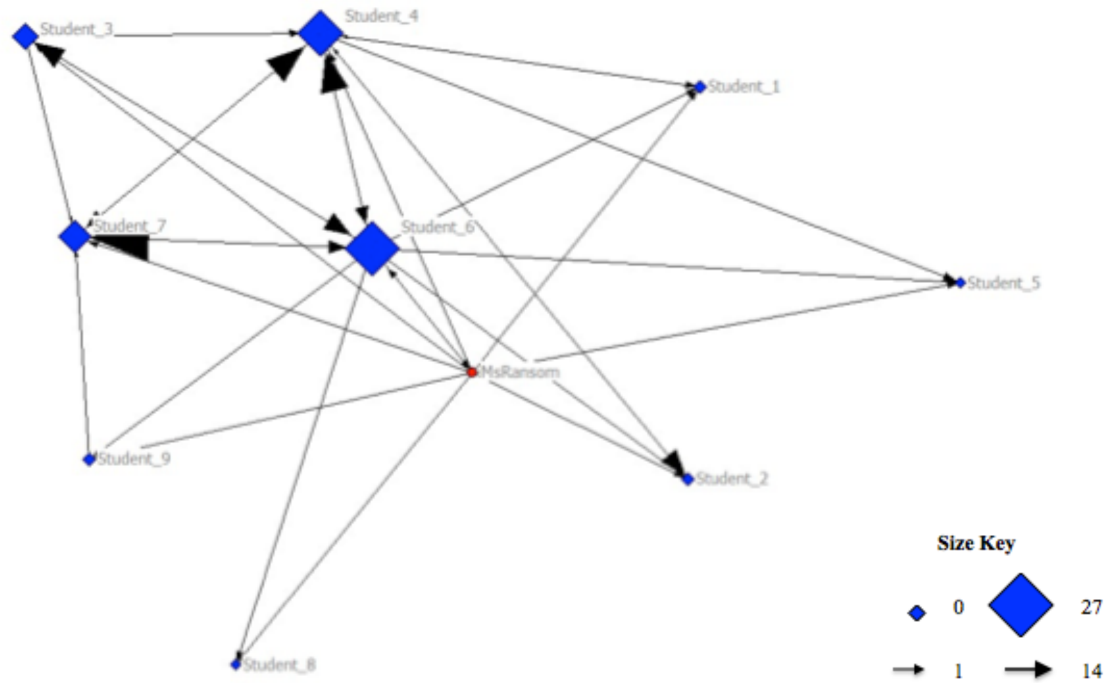


Sociograms of dialogic interactions in Ms. Ransom's class

Group 1



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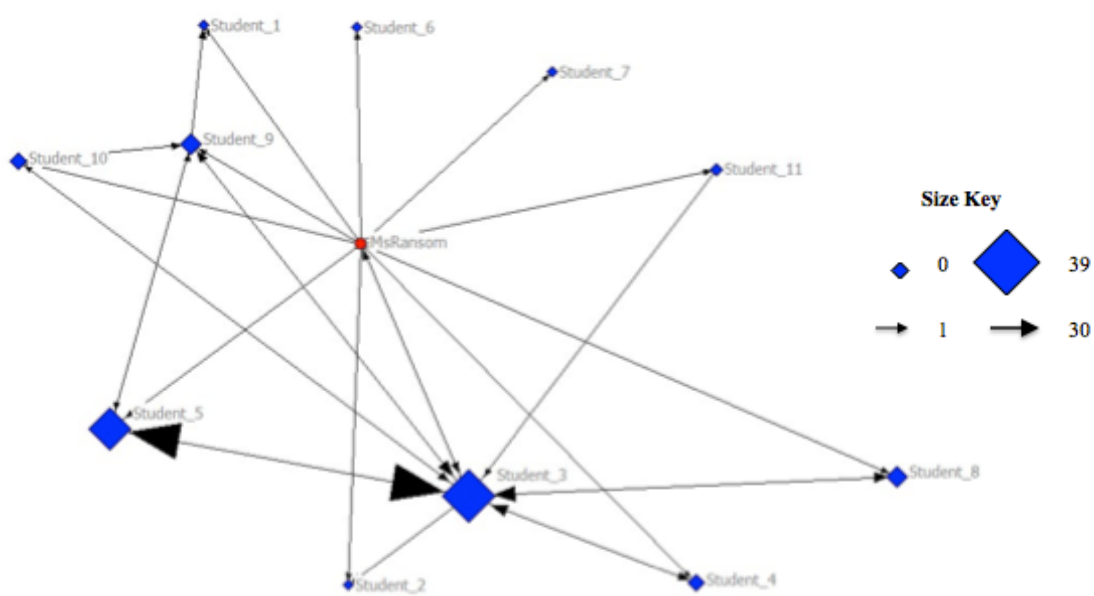
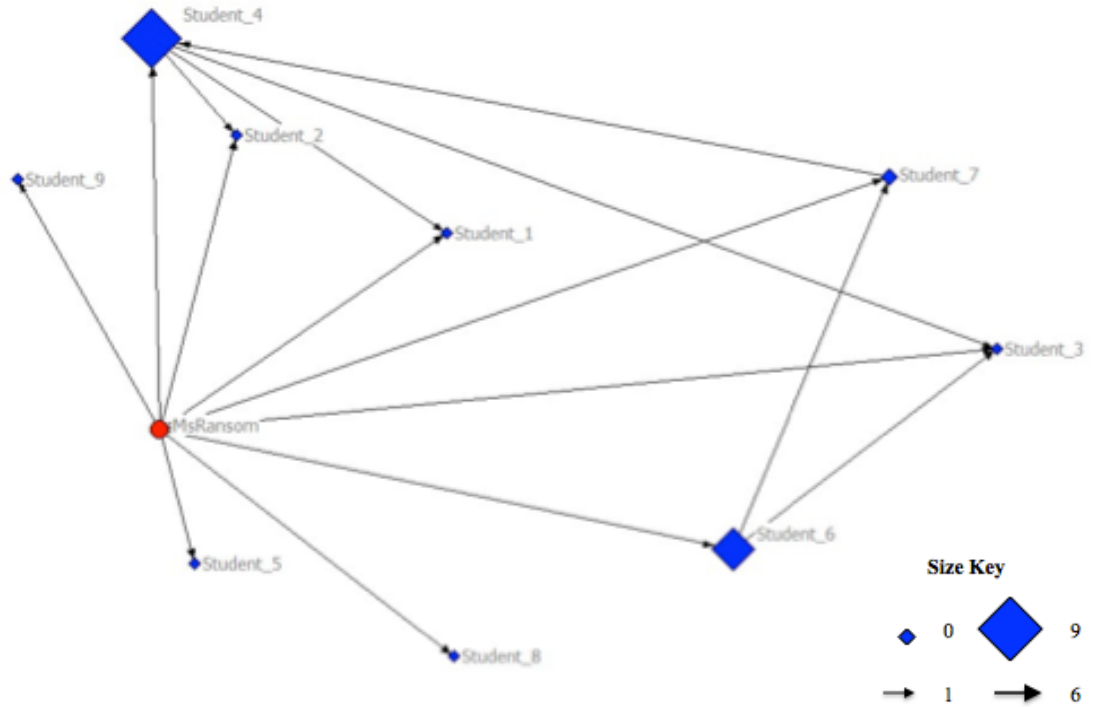


Sociograms of questioning in Ms. Ransom's class

Group 1



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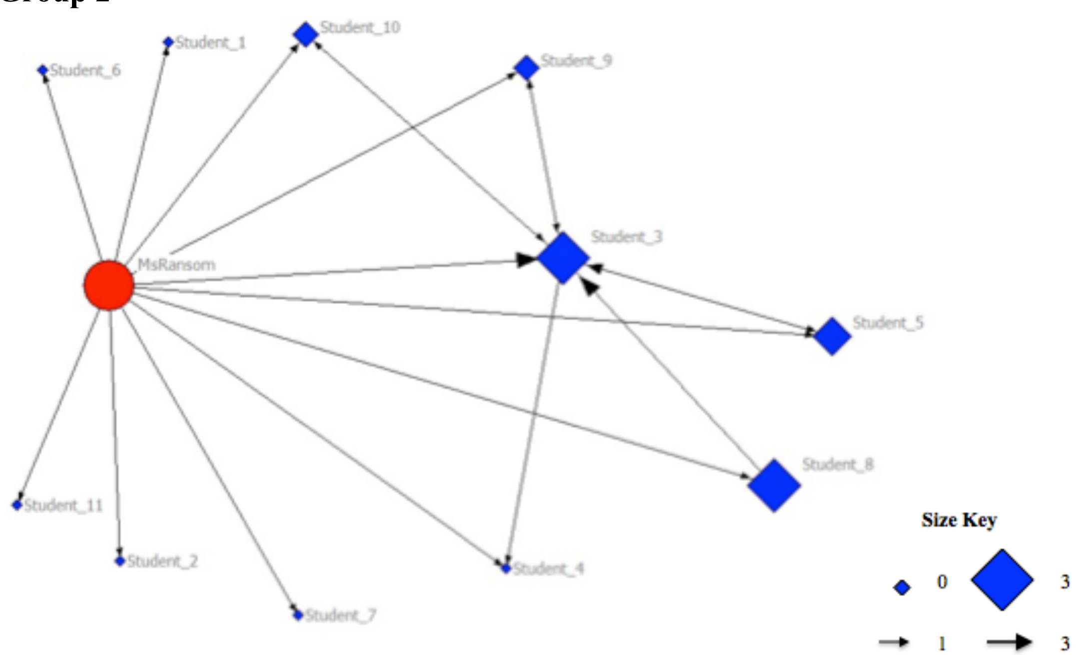
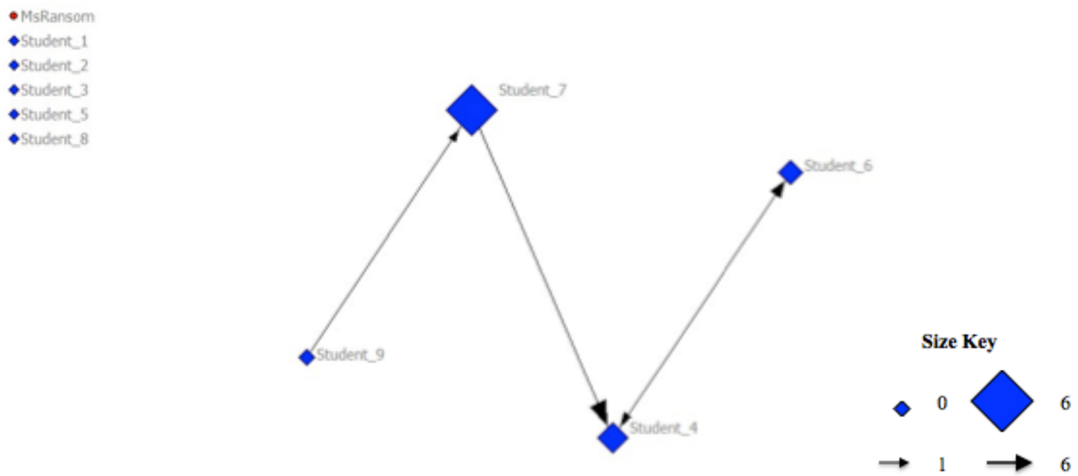


Sociograms of critiquing in Ms. Ransom's class

Group 1



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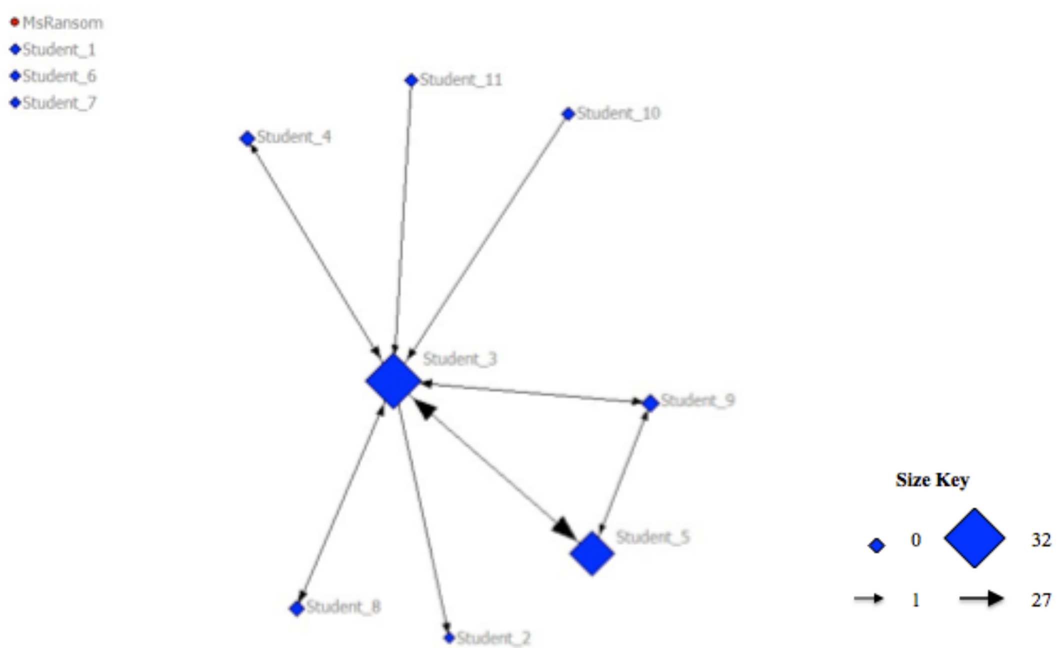
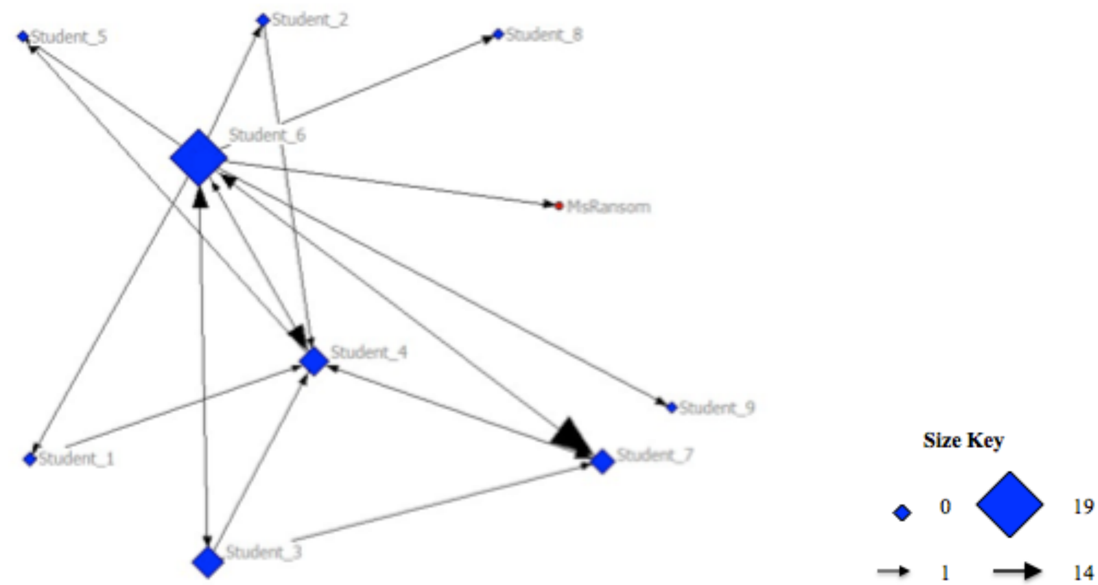


Sociograms of building in Ms. Ransom's class

Group 1



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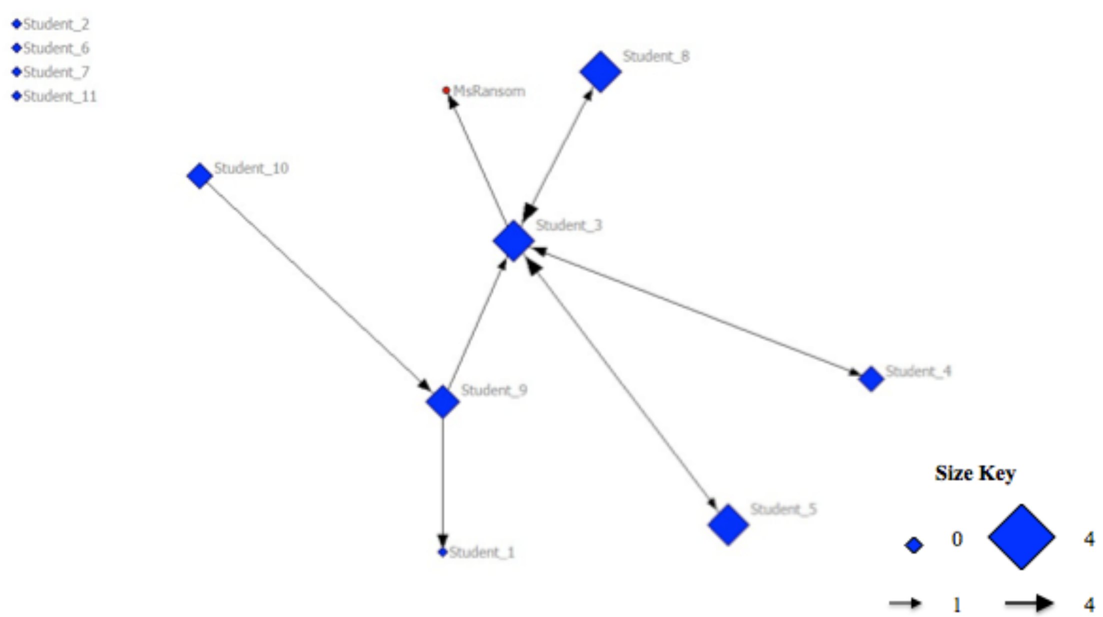
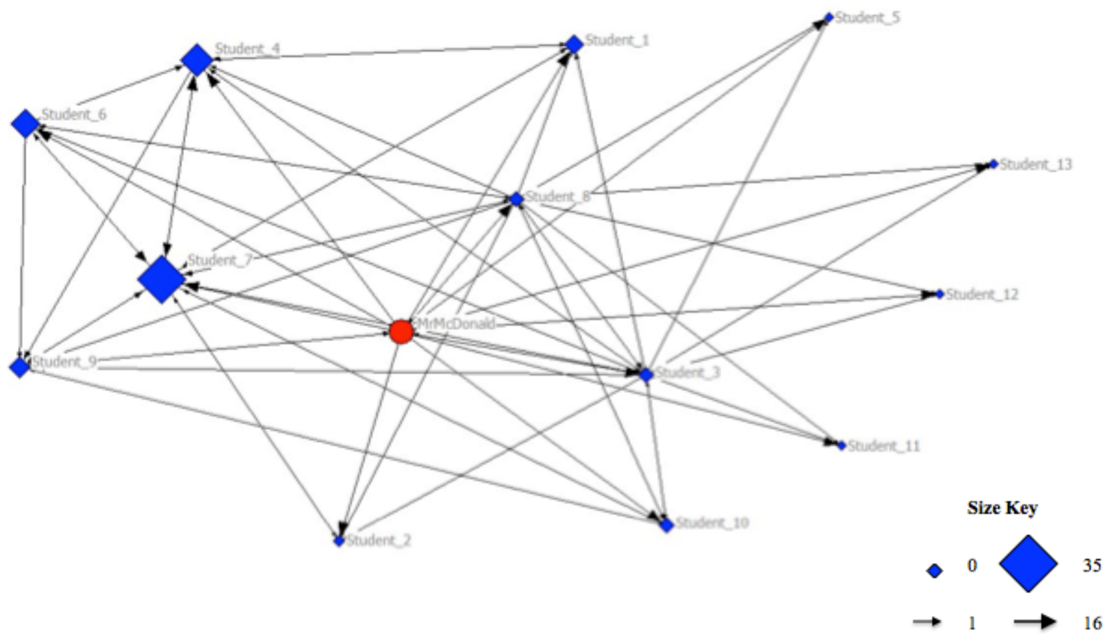


Sociograms of general participation in Mr. McDonald's class

Group 1



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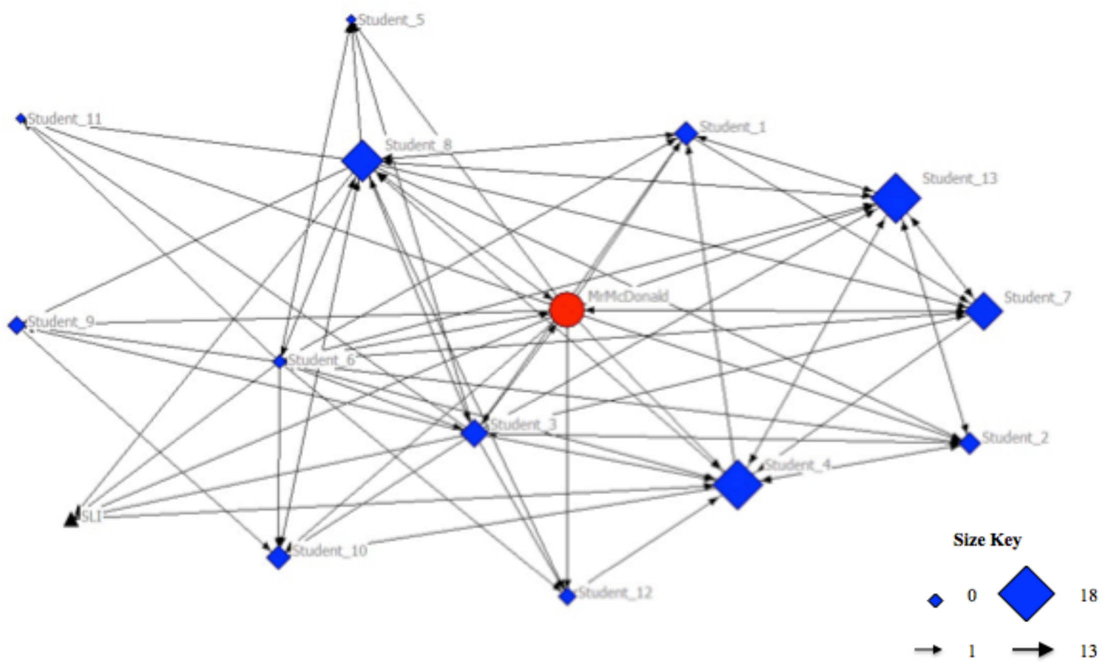
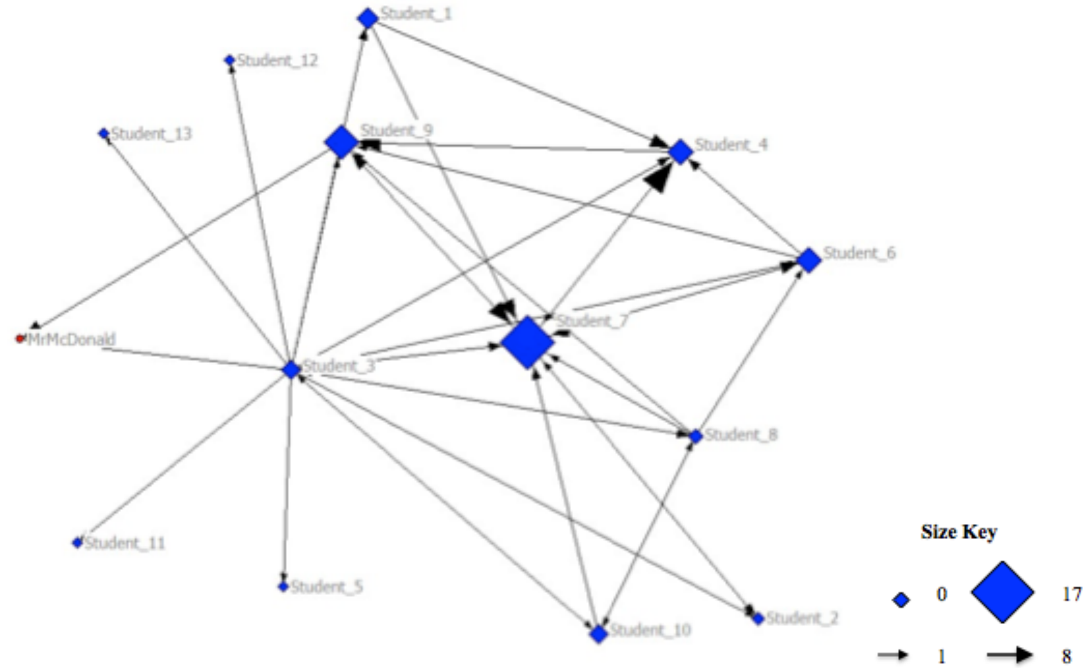


Sociograms of argument structure in Mr. McDonald's class

Group 1



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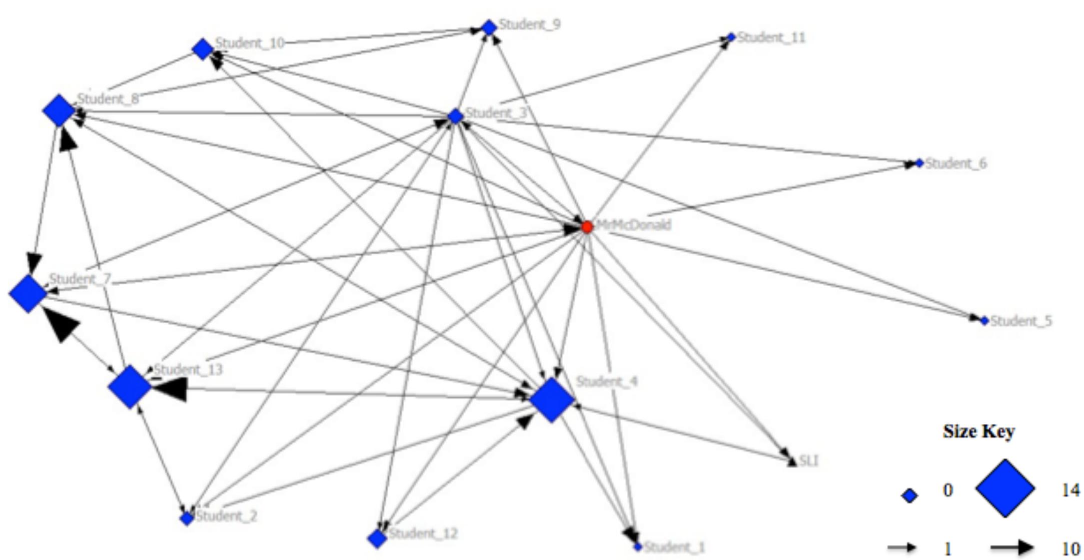
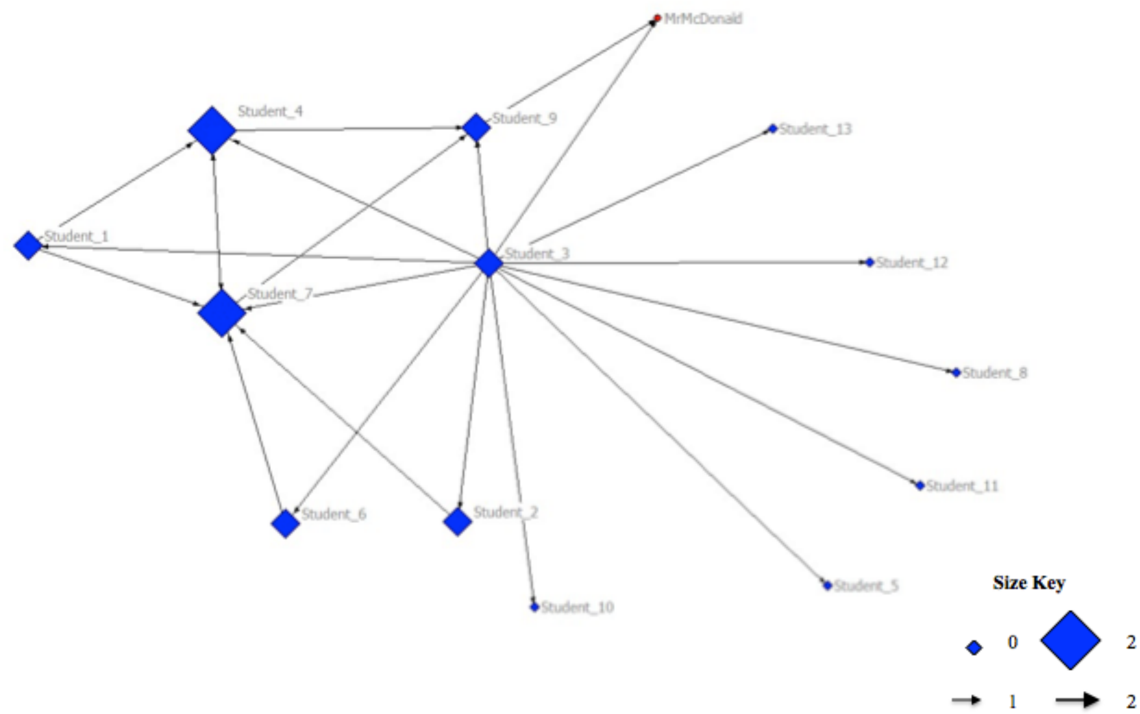


Sociograms of claim in Mr. McDonald's class

Group 1



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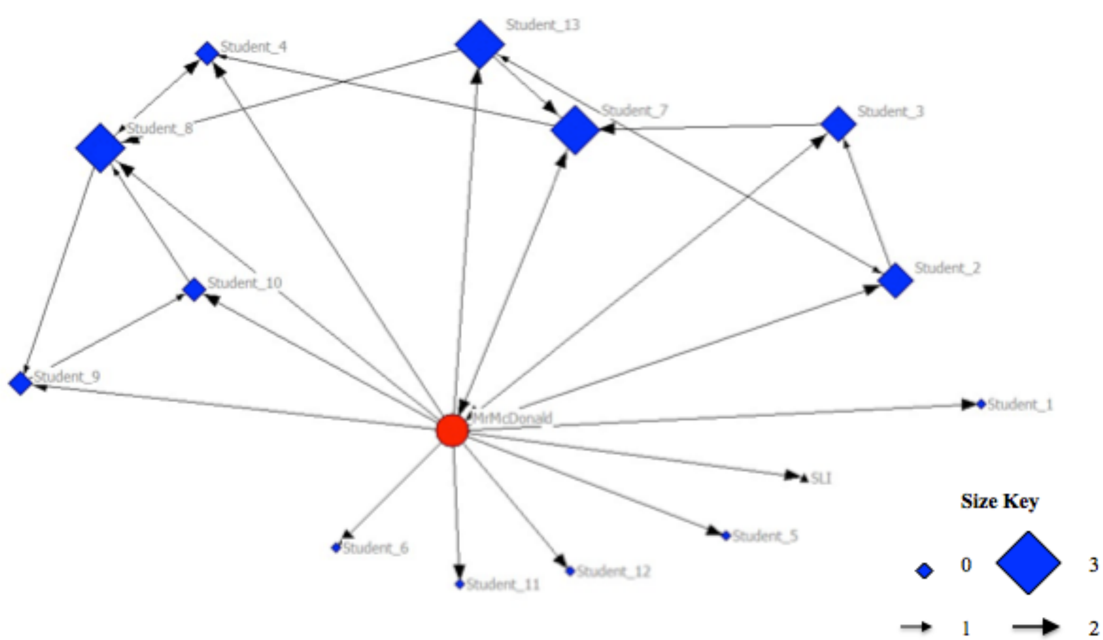
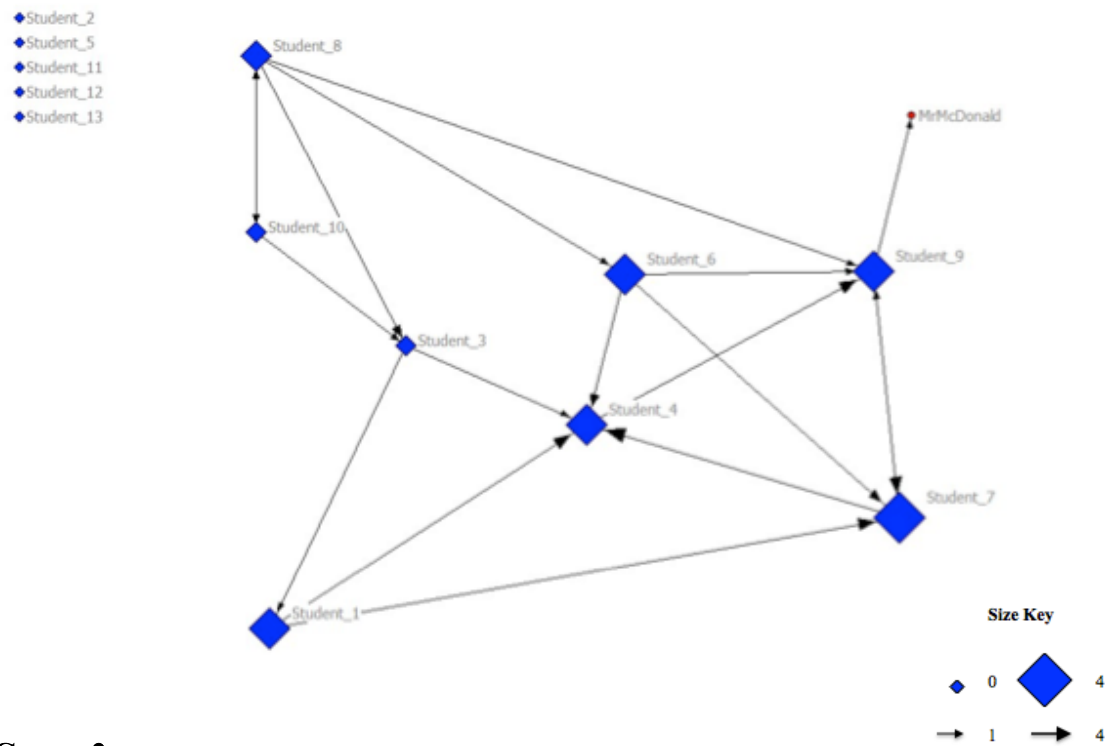


Sociograms of evidence in Mr. McDonald's class

Group 1



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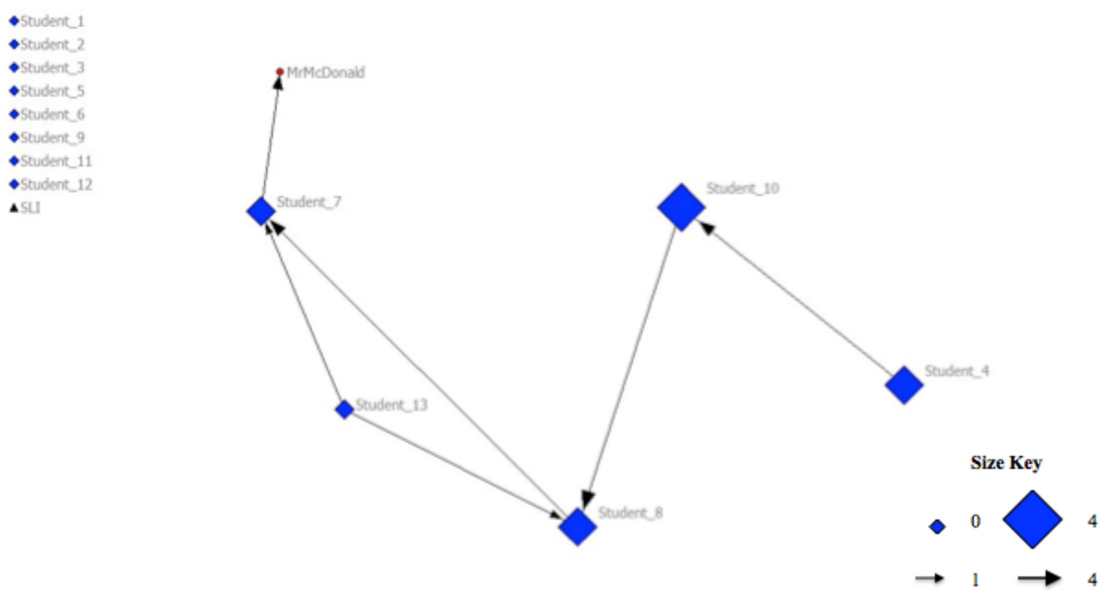
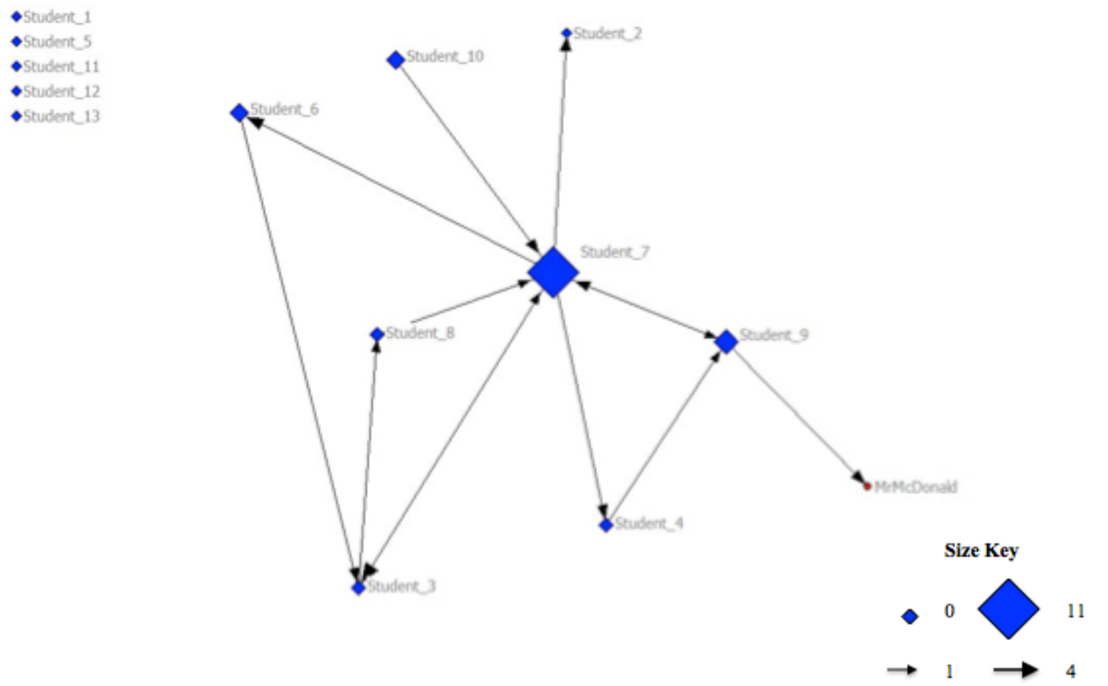


Sociograms of reasoning in Mr. McDonald's class

Group 1



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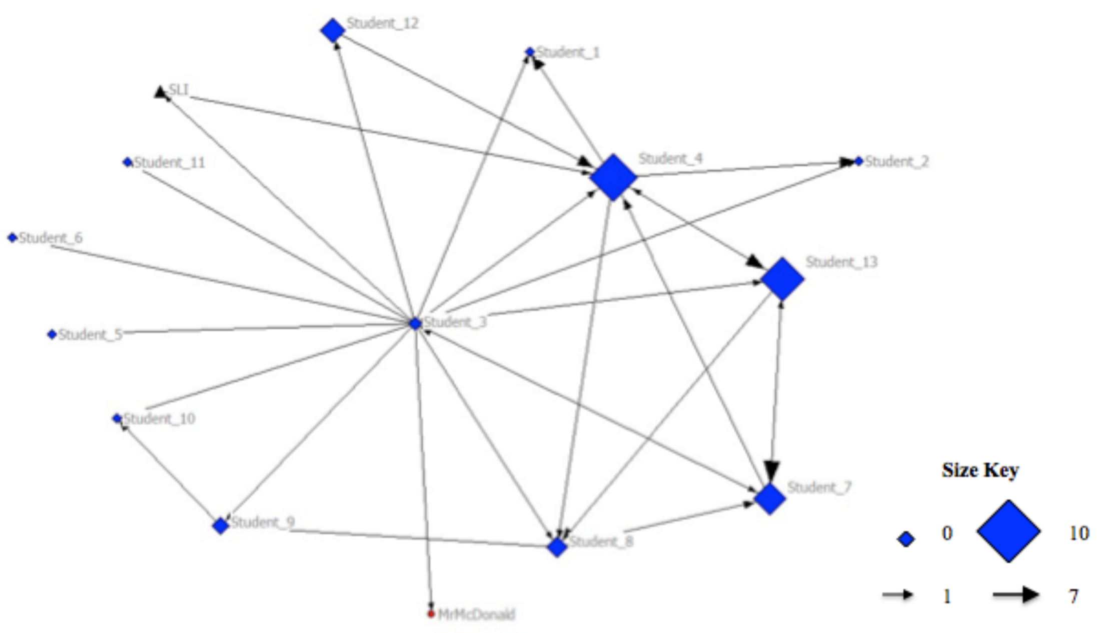
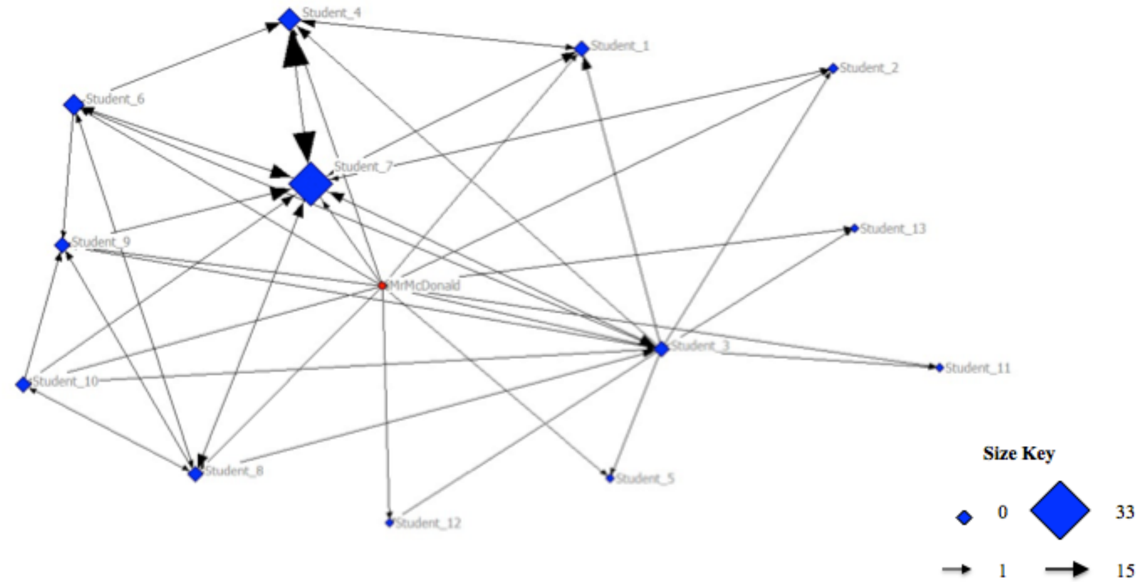


Sociograms of dialogic interactions in Mr. McDonald's class

Group 1



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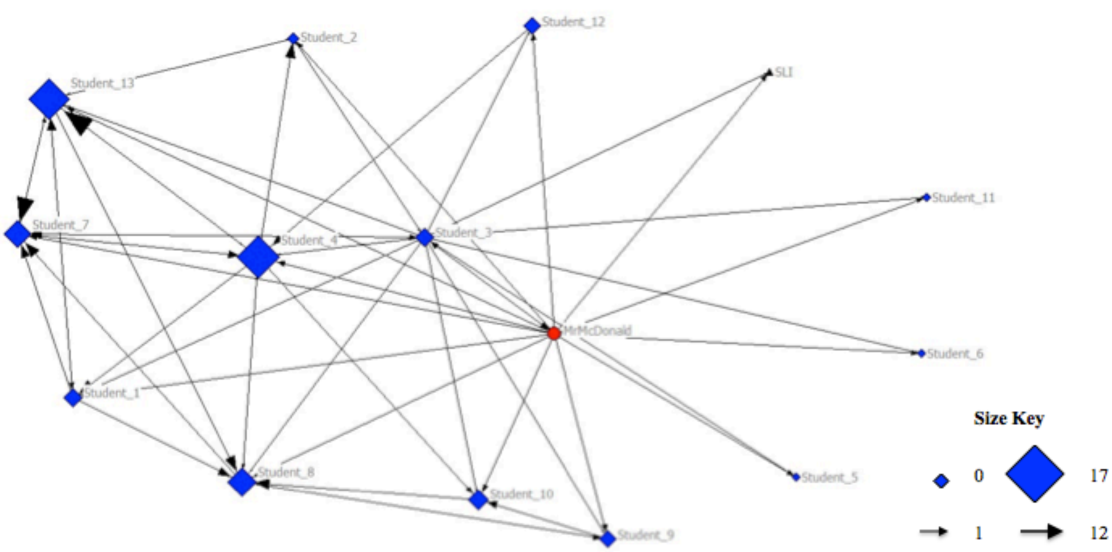
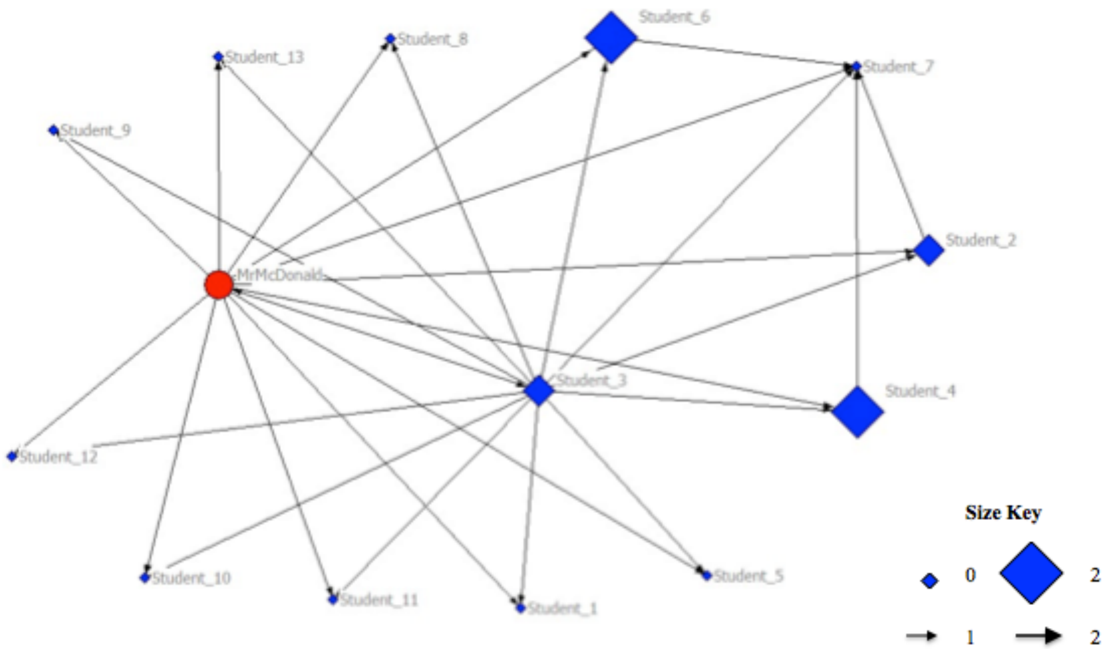


Sociograms of questioning in Mr. McDonald's class

Group 1



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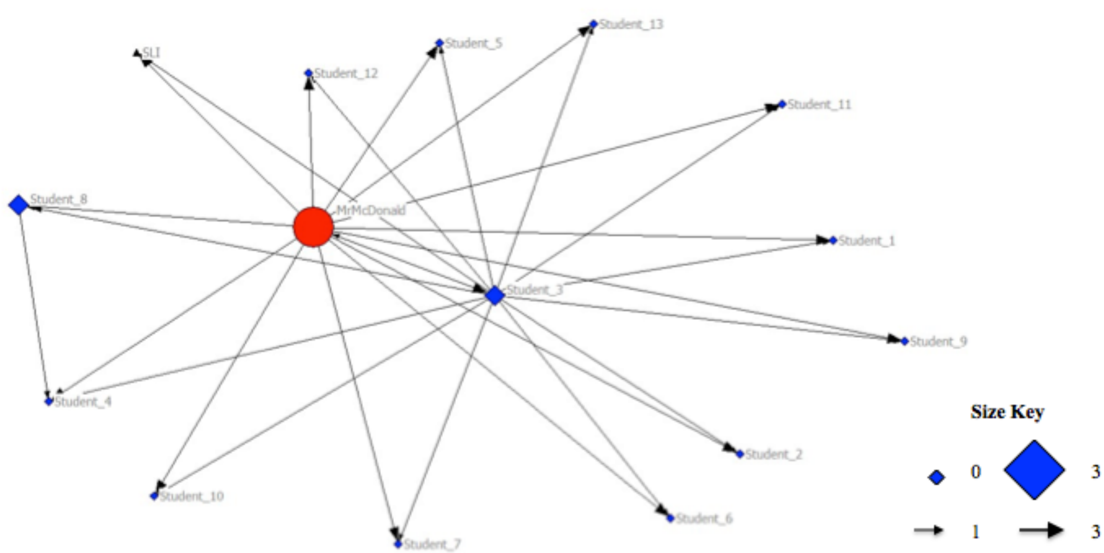
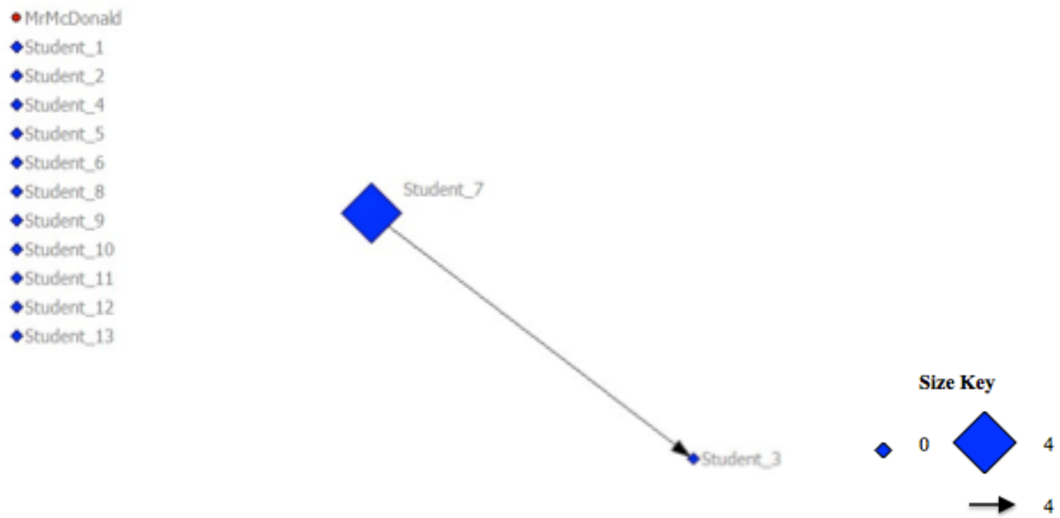


Sociograms of critiquing in Mr. McDonald's class

Group 1



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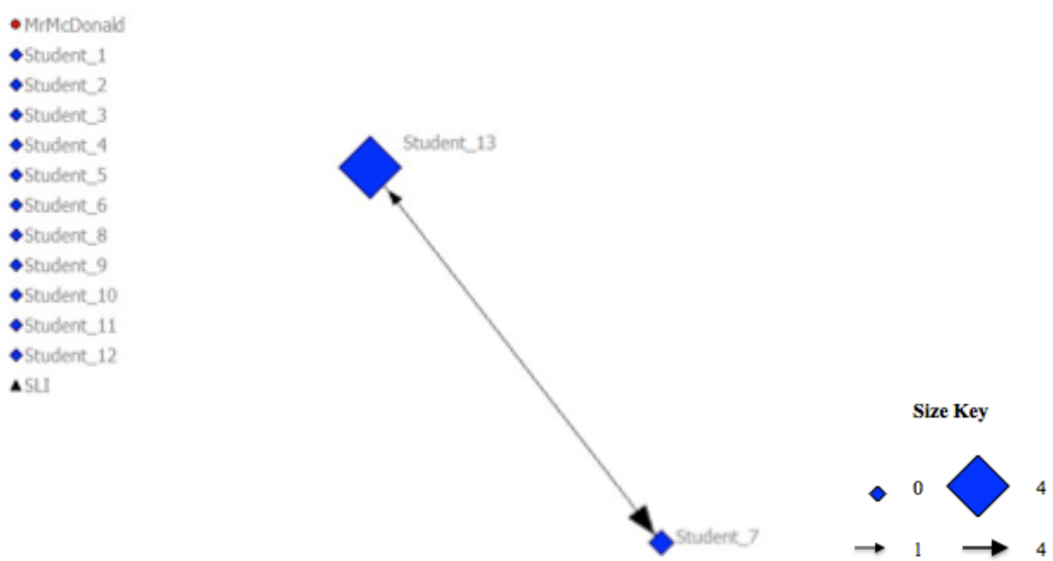
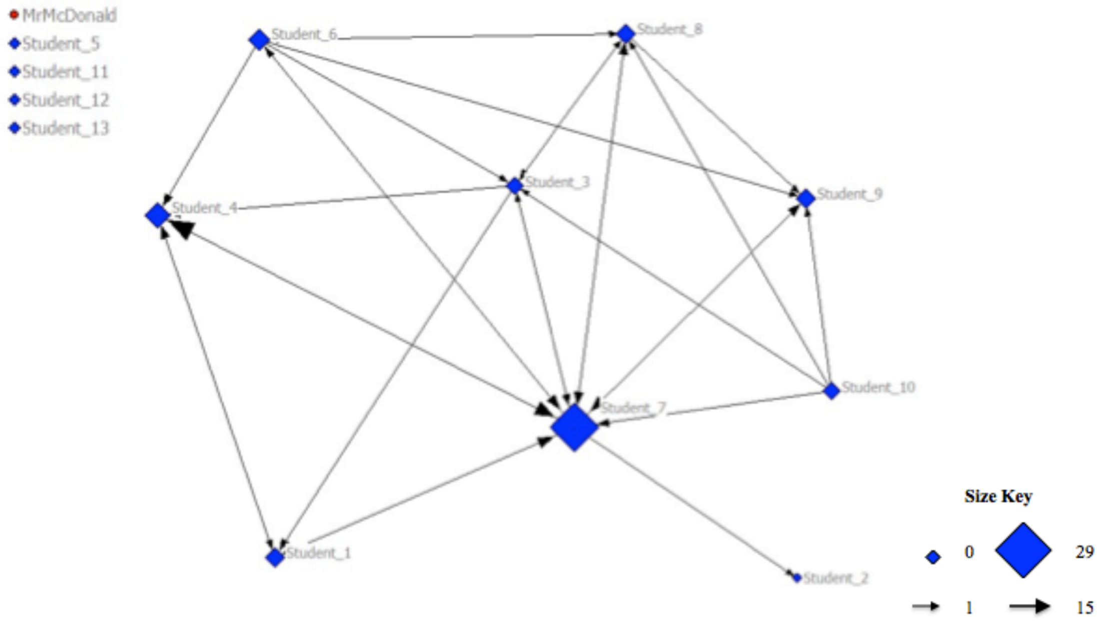


Sociograms of building in Mr. McDonald's class

Group 1



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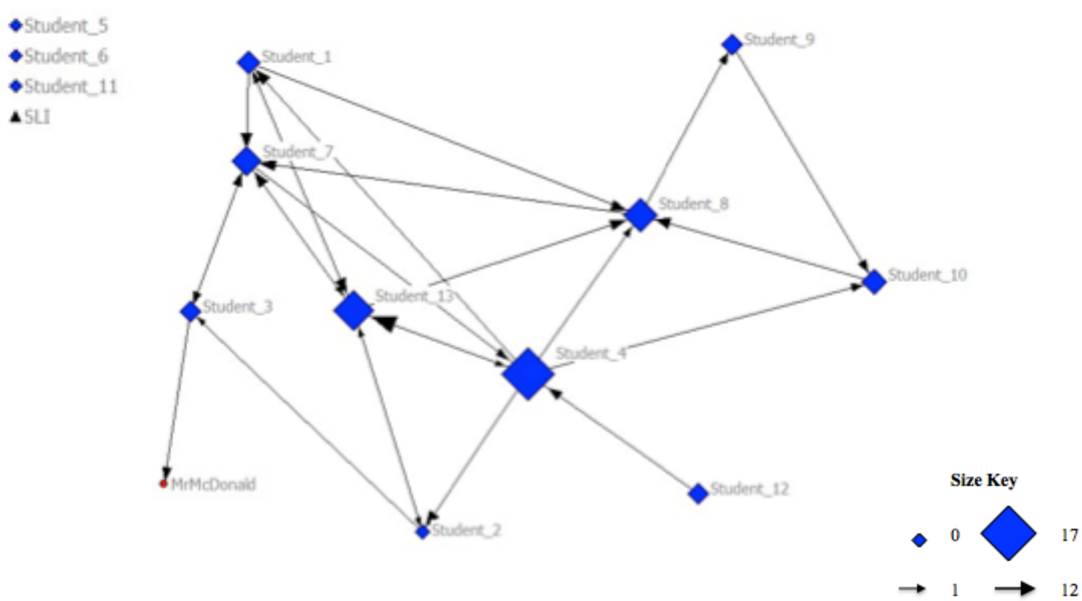
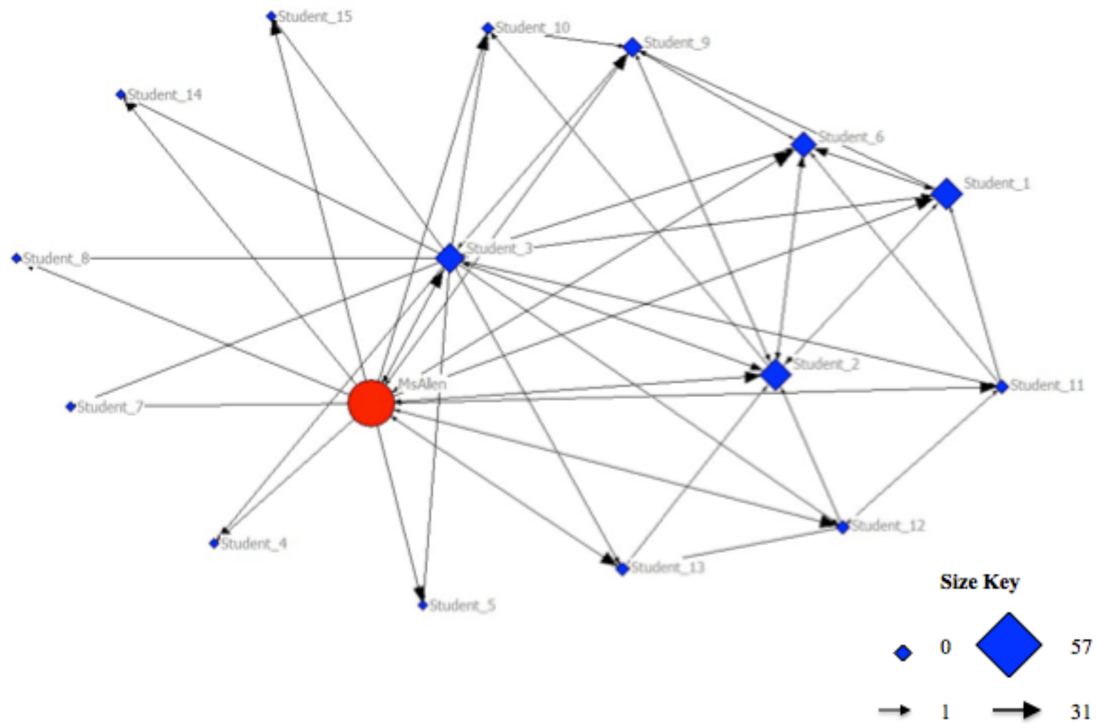


Sociograms of general participation in Ms. Allen's class

Group 1



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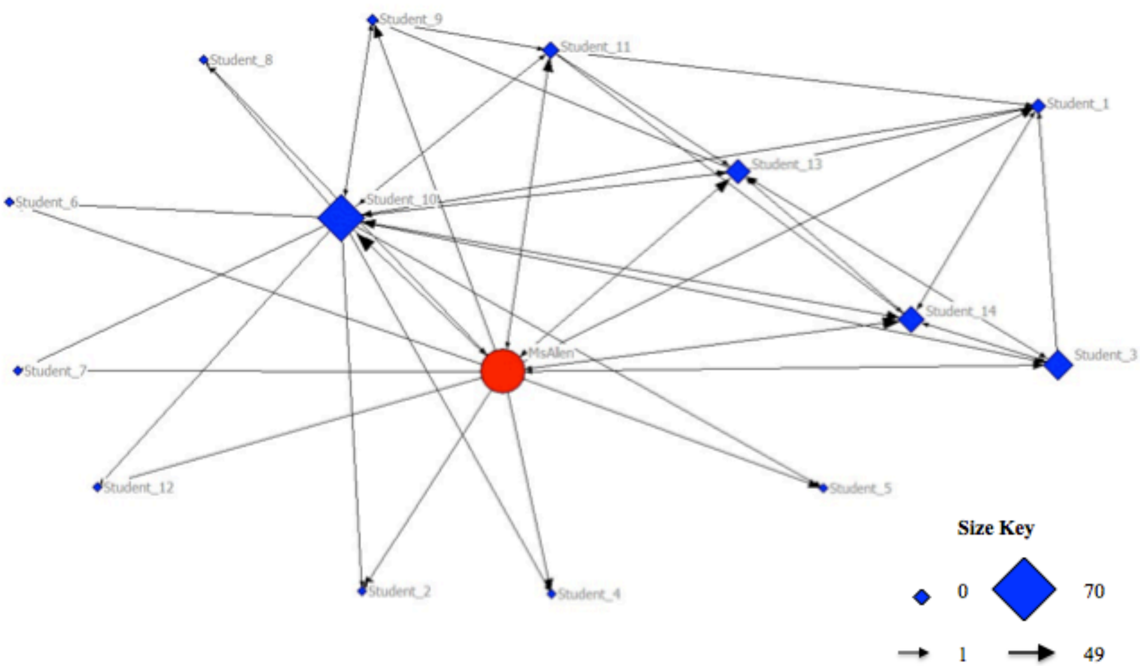
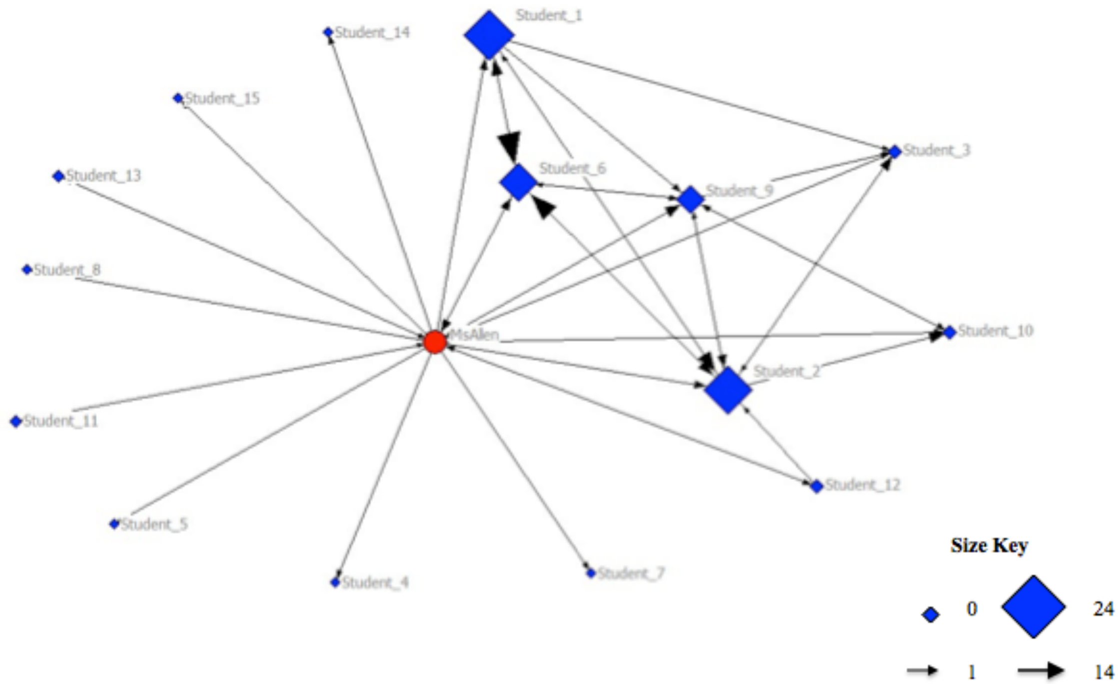


Sociograms of argument structure in Ms. Allen's class

Group 1



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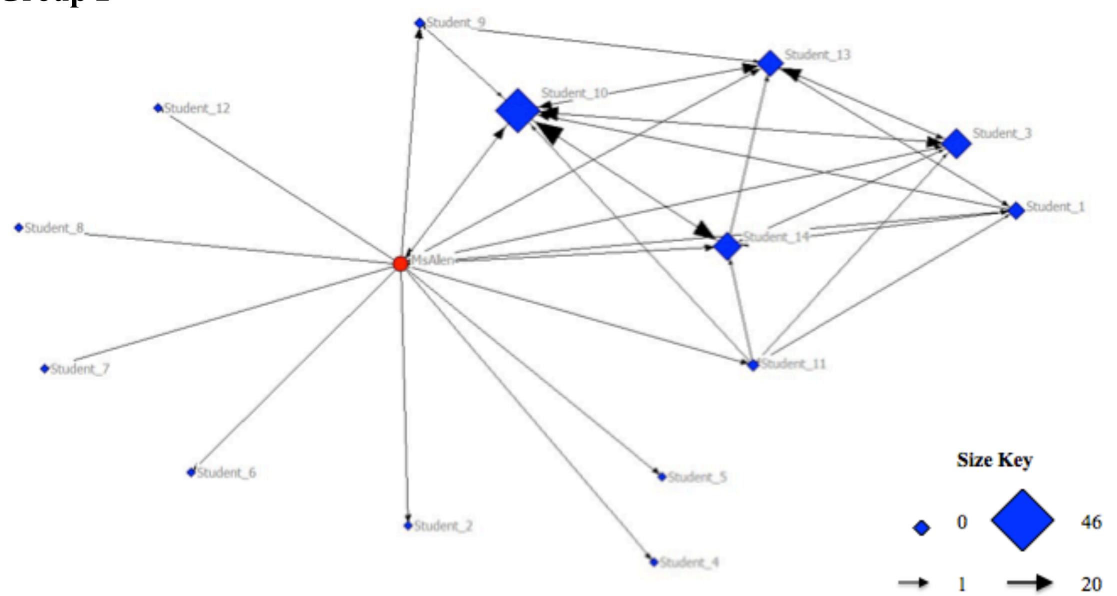
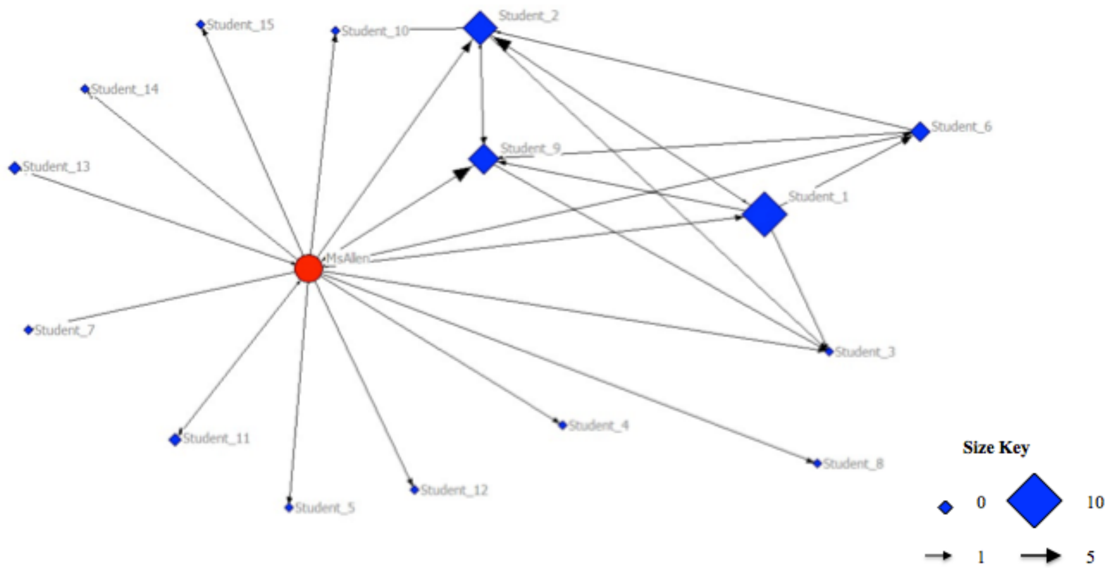
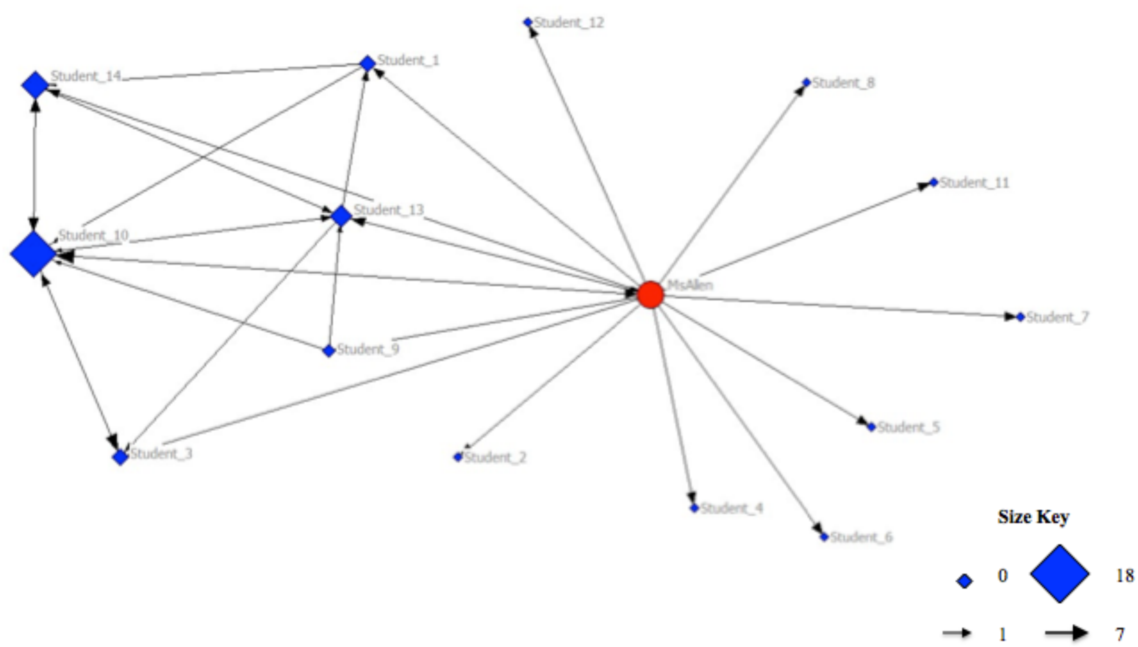


Sociograms of claim in Ms. Allen's class

Group 1

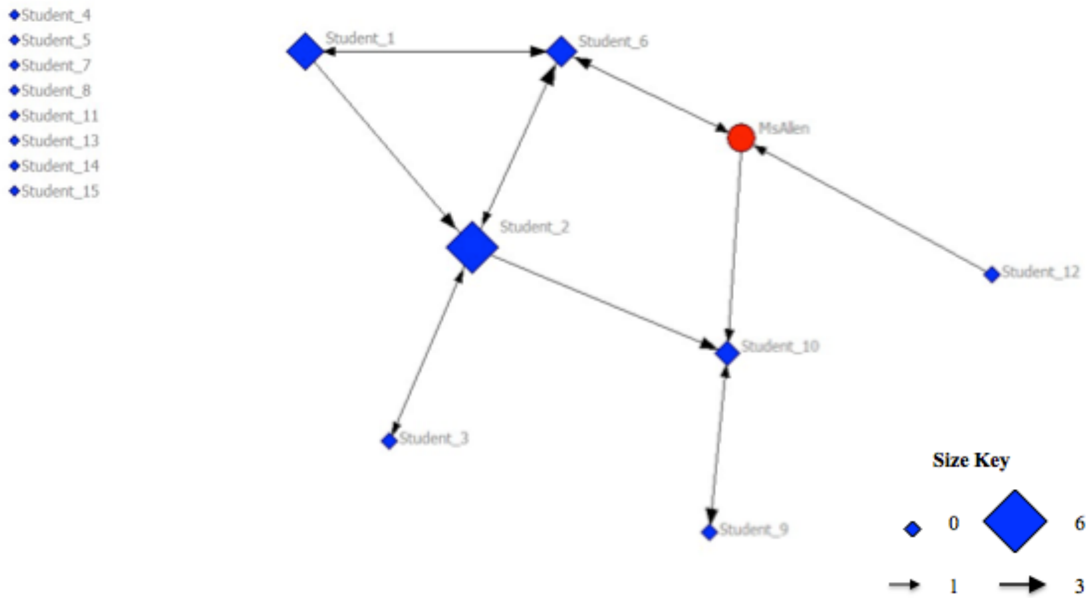


Group 2



Sociograms of evidence in Ms. Allen's class

Group 1



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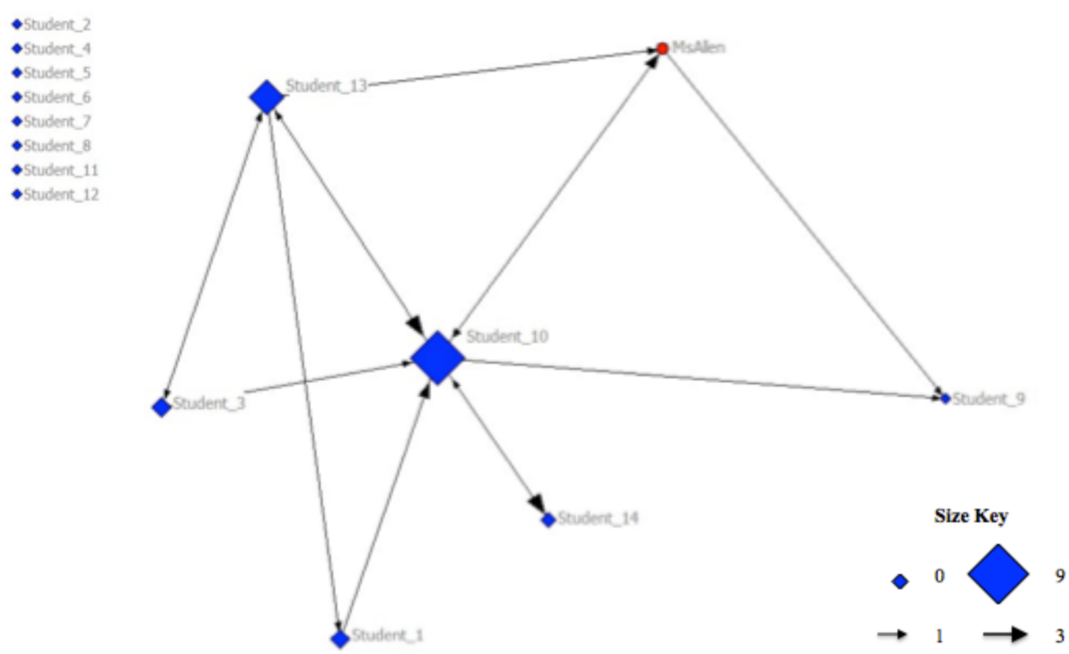
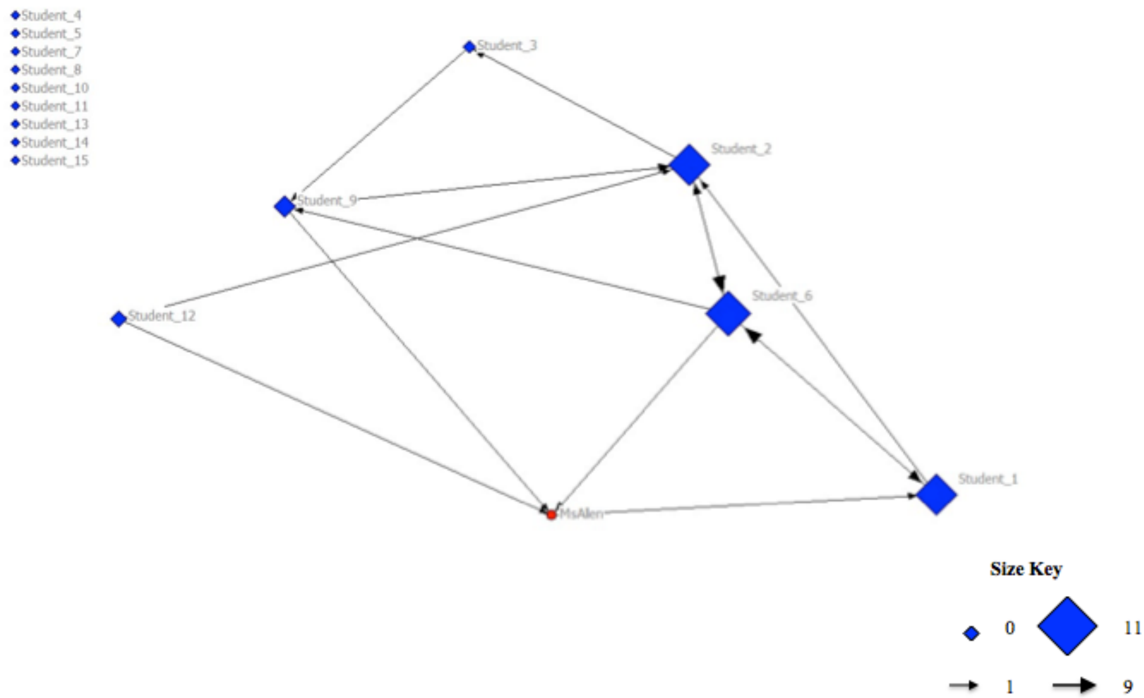


Group 1



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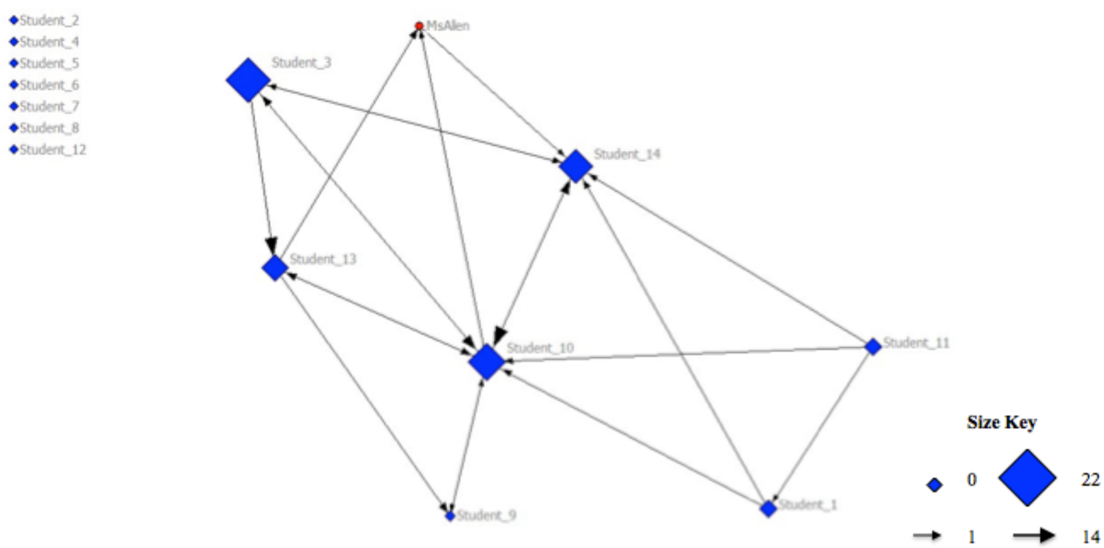
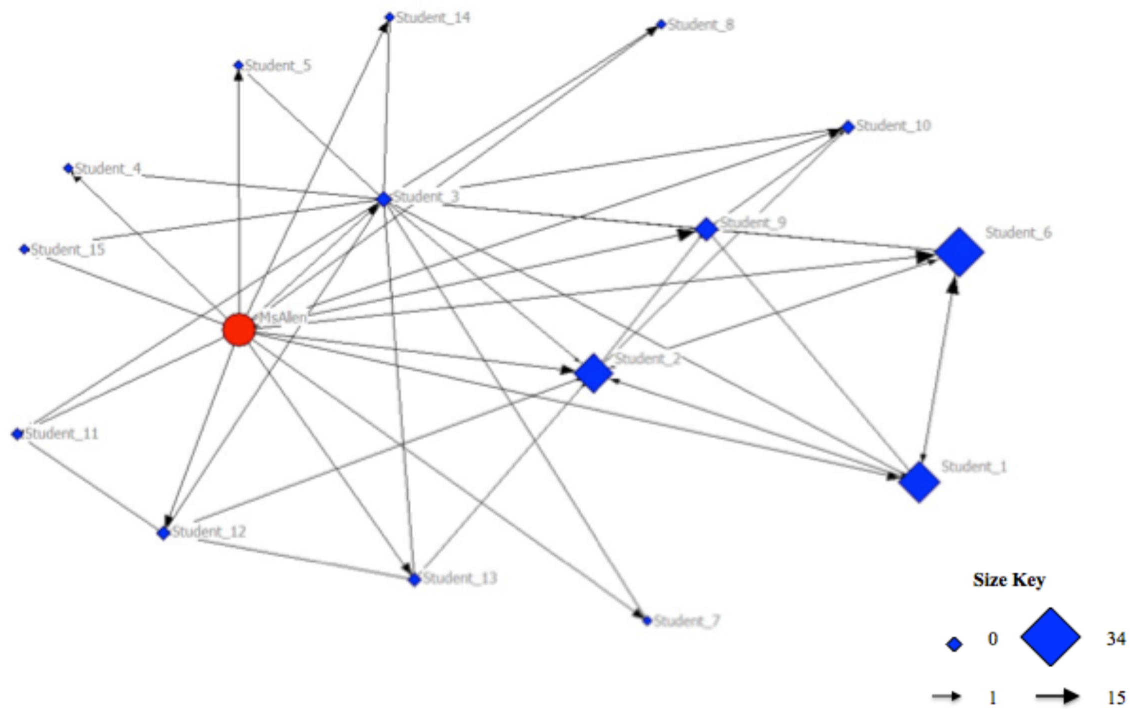


Sociograms of dialogic interactions in Ms. Allen's class

Group 1



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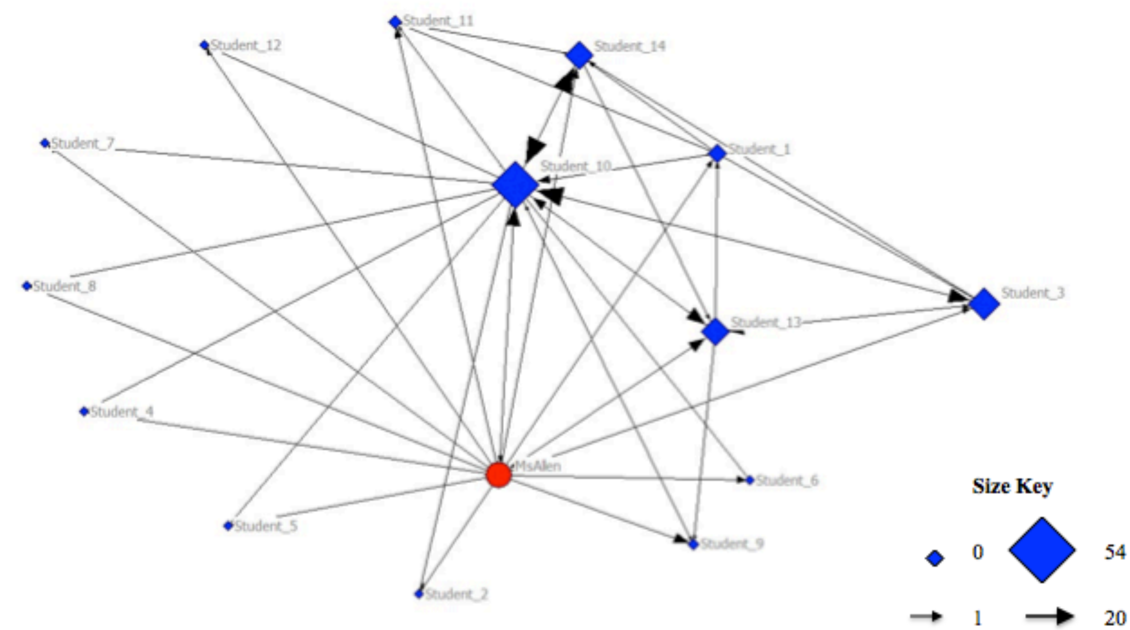
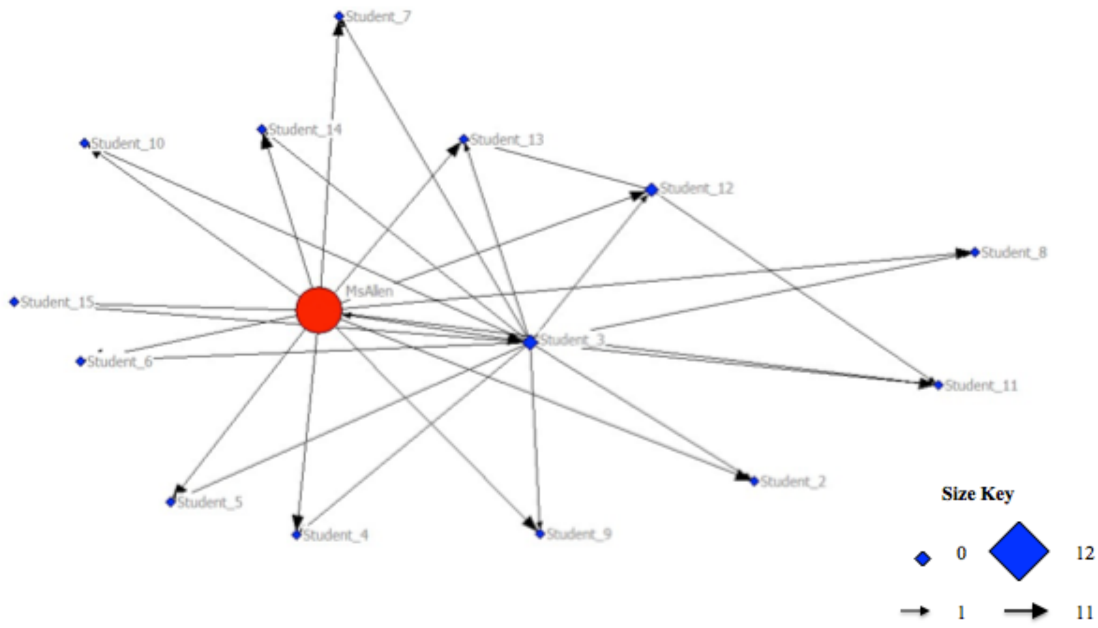


Sociograms of questioning in Ms. Allen's class

Group 1



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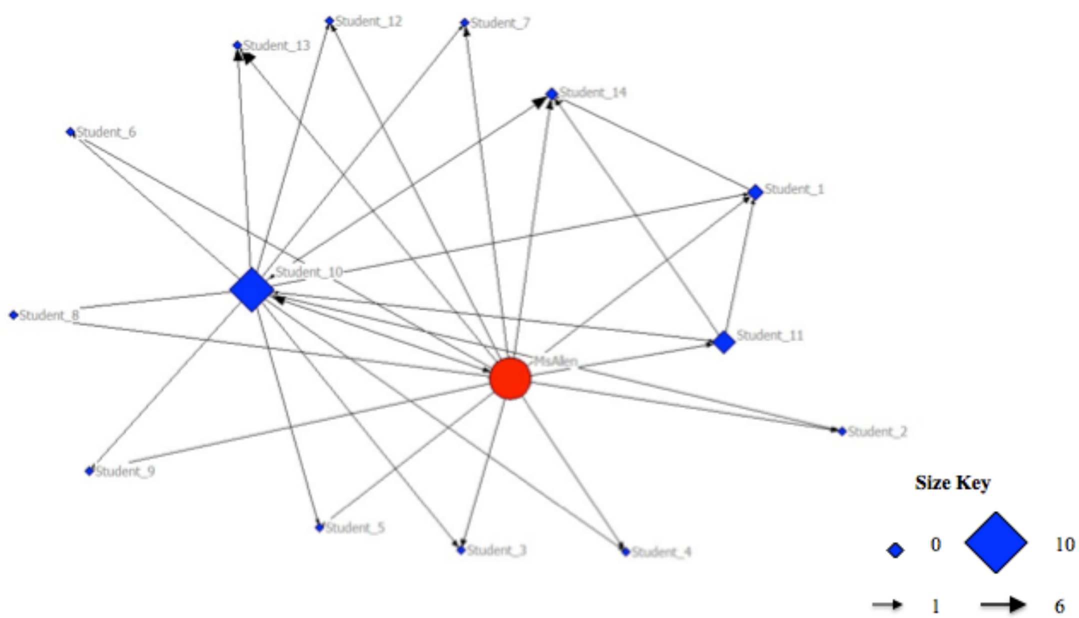
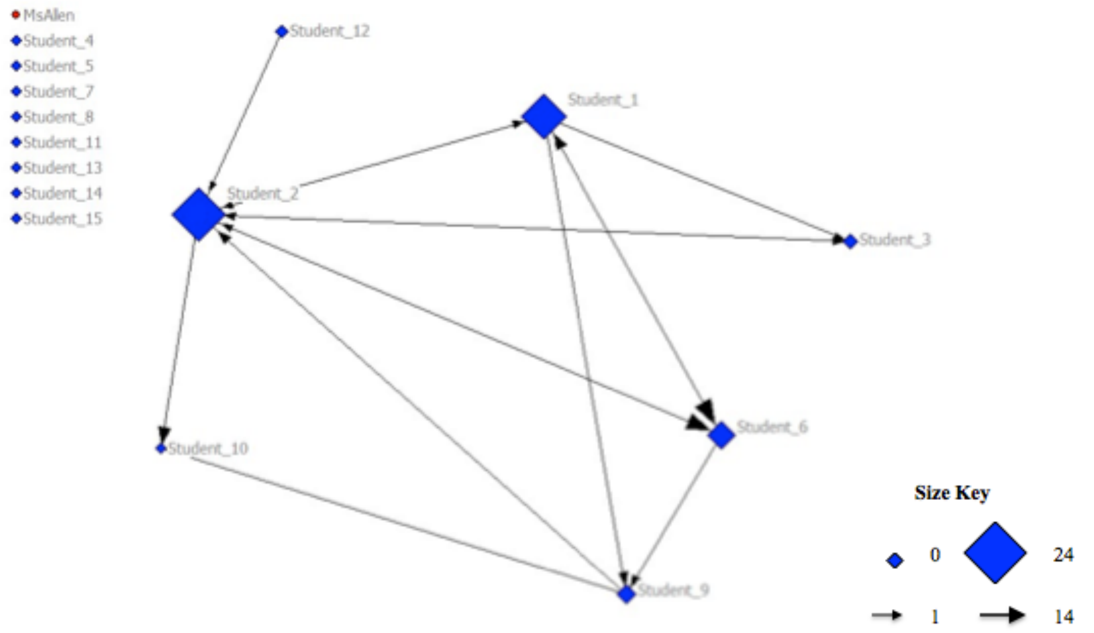


Sociograms of critiquing in Ms. Allen's class

Group 1



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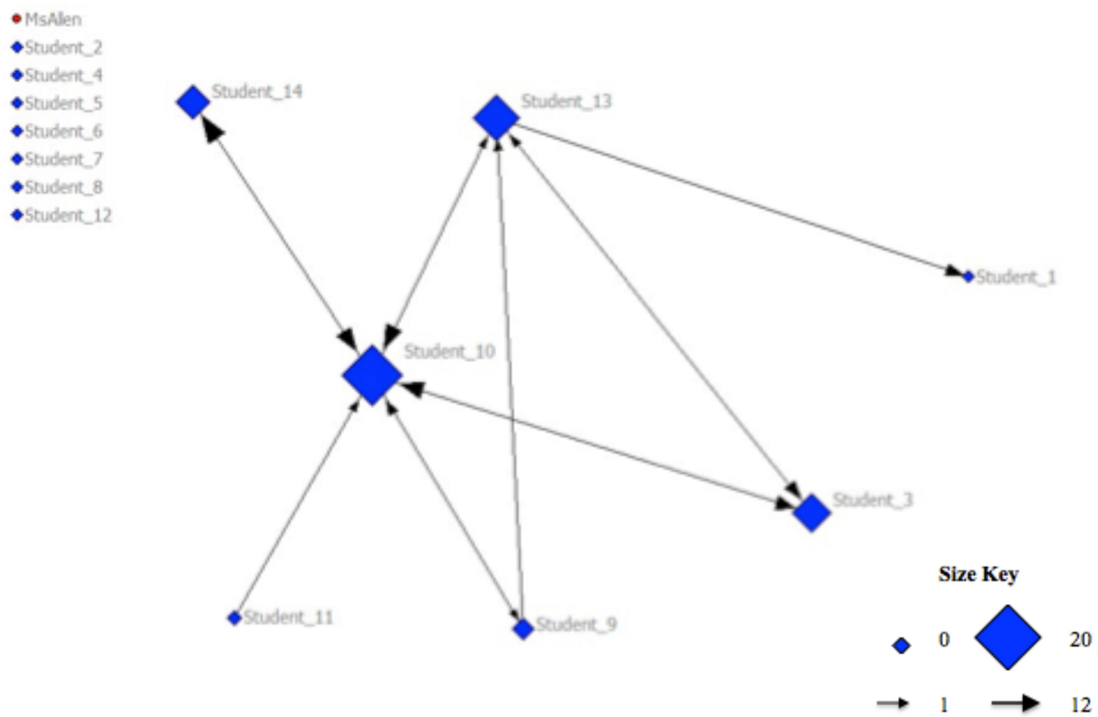
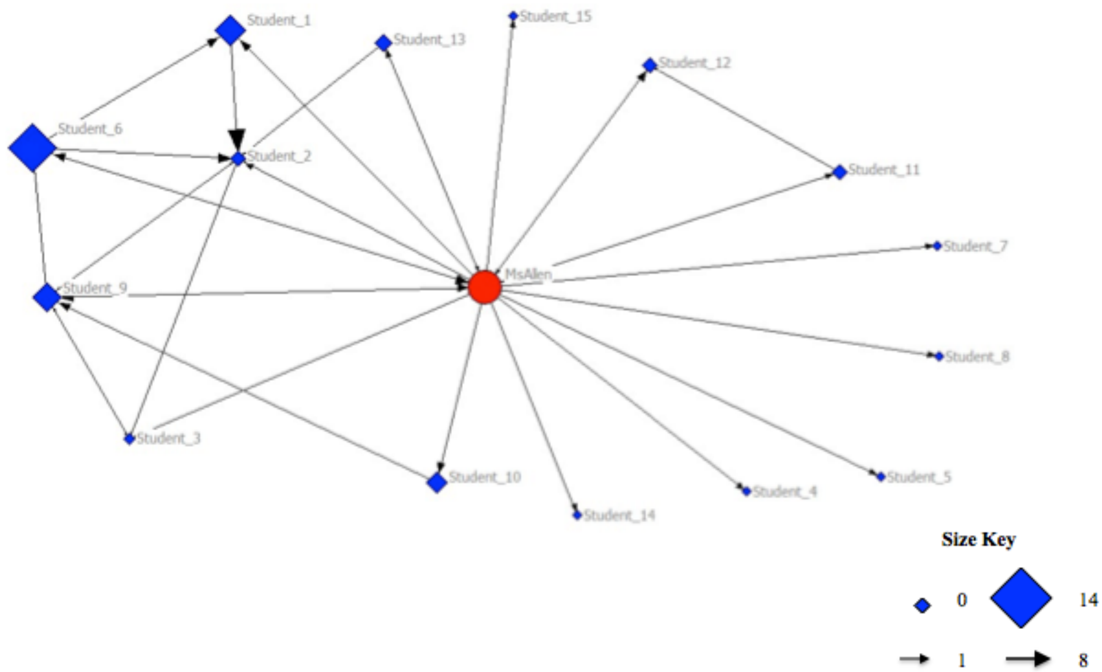


Sociograms of building in Ms. Allen's class

Group 1



Group 2