STUDENT-GENERATED QUESTIONS IN INQUIRY SCIENCE: CONNECTING TO COLLABORATIVE ARGUMENTATION

Lana M. Minshew

A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctorate of Education in the School of Education (Learning Sciences and Psychological Studies).

Chapel Hill
2018

Approved by:
Janice L. Anderson
Sharon J. Derry
Lynda Stone
Kelly Ryoo
Margaret R. Blanchard
ABSTRACT

LANA MARIE MINSHEW: Student-Generated Questions in Inquiry Science: Connecting to Collaborative Argumentation
(Under the direction of Janice L. Anderson)

The National Research Council (NRC) released the Next Generation Science Standards (NGSS Lead States, 2013) that established a framework for three-dimensional learning, which includes science and engineering practices, crosscutting concepts, and disciplinary core ideas. The first dimension of learning emphasizes scientific and engineering practices asserting that students should not only be familiar with scientific practices but also be able to successfully conduct an investigation utilizing the practices (NGSS Lead States, 2013). The science practices were included in the NGSS because knowing science content is not enough; students need to be able to use their understanding to investigate the natural world (NGSS Lead States, 2013). The expectation is that students not just know science content but can participate in science exploration and the many discourses of science. The scientific practices intentionally overlap one another and are interconnected; they do not operate in isolation (NGSS Lead States, 2013). However, little is known about how the scientific practices overlap, specifically how one scientific practice influences another. Studies often focus on students’ development or implementation of a single scientific practice such as developing and using models or engaging in argumentation. This dissertation study aimed to examine the relationship between questions posed and dialogical arguments constructed by students during collaborative work in small groups during a designed curricular unit titled Compost. The focus was on questions and
dialogical arguments that arose naturally as students’ participated in a collaborative project-based inquiry science curriculum. The data from this study showed that students’ questions helped them to navigate the science content presented in the Compost curricular unit. Students’ questions directed student thinking by enabling them to share their prior knowledge, identify points of uncertainty, challenge each others’ ideas, as well as generate and occasionally sustain increasingly complex instances of argumentation.
This work is dedicated to my Mom and Dad, who have always supported me and have been my biggest cheerleaders from the beginning. Their positive energy, love for my brother and I, and their tireless efforts to be amazing teachers have been my source of inspiration and dedication in doing this work.
ACKNOWLEDGEMENTS

I have many people to thank for their unwavering support during the completion of my doctoral degree and this dissertation. First, my deepest gratitude goes to my advisor, Janice Anderson, thank you for always having an open door, providing me with endless opportunities for research, and being both supportive and critical of my growing knowledge and ideas. Your guidance through this process has been amazing and I cannot image working and thinking alongside anyone else. Next, I want to thank the rest of my committee, your help and guidance have made me a better researcher, thinker, and writer. I appreciate your time and effort in helping me in my journey. To Sharon Derry, thank you for always pushing me to produce my best work. You have been a crucial figure in making me a better researcher and scholar. You also make one hell of a travel partner. I would also like to thank the others, including Lynda Stone, Kelly Ryoo, and Meg Blanchard, who graciously served on my committee and provided valuable feedback and guidance during this research project.

My pursuit of a doctorate degree would not have been possible without the constant love and support from my family. To my parents for encouraging me to pursue my dreams, whatever they may be. Without your continued encouragement the path I’ve chosen to travel would have been infinitely more difficult. To my brother, Nathan, for keeping me grounded in reality. And for always reminding me that our parents have two incredibly brilliant children and he is one of them. To my grandparents who constantly reminded me that they are proud of me despite not really knowing what exactly it is I’m doing. Thank you for instinctively knowing that I would be
great and providing affirmation every chance you got. To my niece, Emilee, for making me take a break from my studies and research so I could just have fun with her. You and me are one in the same kid; don’t ever stop smiling and having fun.

To all of my friends both near and far I could not have made it through this without you. To Sami, for always listening to me and allowing me to vent whenever I needed to. For correcting my abhorrent use of commas and making multiple trips to North Carolina and my parents’ house just to spend time with me. To my little-buddy, Kelly, for wearing me down and forcing me to accept hugs and her friendship. You have no idea how much harder this process would have been if you hadn’t infiltrated my life. To Molly, for keeping me sane during my last few milestones of graduate school and being there to just hang out, drink wine, and not talk about graduate school. To Kayley, Kristin, Emily, Audra, and Liz thank you for friendship, taking time to be supportive of each other, and simply checking in to make sure shit hadn’t hit the fan. To Beth, Suzy, and Laura, thanks for reminding me to have fun and pulling me out the door to have it. Thank you to my many other SOE friends that I haven’t listed but have all been influential to me during my time at UNC.

Finally, to my amazing partner, Jared, you have been wonderful since the moment we met. You have navigated my seemingly endless work hours, my stress, tears, and anxiety, and yet only seem to love me more as time progressed. Thank you for standing strong next to me, providing on-demand hugs, and being my rock. I love you and I like you.
# TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................... xiii

LIST OF FIGURES ......................................................................................................... xv

I. ASKING QUESTIONS & ARGUMENTATION: INTRODUCTION & OVERVIEW……… 1

Statement of Problem ................................................................................................. 3

Aim of Study & Research Questions ........................................................................... 6

Significance of Study ..................................................................................................... 7

Research Design ........................................................................................................... 8

Limitations .................................................................................................................... 8

Chapter One Summary and Overview ....................................................................... 9

Definition of Terms ..................................................................................................... 10

II. REVIEW OF LITERATURE: ARGUMENTATION AND ASKING QUESTIONS IN

SCIENCE EDUCATION ................................................................................................. 12

Conceptual Framework ............................................................................................... 12

Scientific Argumentation ............................................................................................. 14

Asking Questions ......................................................................................................... 17

Asking Questions and Scientific Argumentation ....................................................... 27

III. EXAMING STUDENTS QUESTION & SCIENTIFIC ARGUMENTATION:

METHODOLOGY ........................................................................................................... 30

Research Design ......................................................................................................... 30
Argumentation & The Making Observations (Card Sort) Activity ..................73
Simple Claims .................................................................74
Increasing complexity of arguments ...........................................75
Case Summary .......................................................................82
Case 2 - What Factors Help Decomposers Break Down Matter? –
What Factors? Activity ............................................................84
Description of Activity ............................................................84
Questioning & The What Factors? Activity .................................86
Inquiry/Science Content-focused questions .................................87
Argumentation & The What Factors? Activity ..............................91
Low instances of argumentation .................................................91
I-2 Male group, the exception..................................................95
Case Summary .......................................................................98
Case 3 - Virtual Experiments – Moisture Level & Carbon to Nitrogen Ratio ........99
Description of Activity ............................................................99
Questions & The Virtual Experiments ........................................104
Implementation 1 – Moisture Virtual Experiment ............................105
Implementation 2 – Carbon to Nitrogen Virtual Experiment ............107
Argumentation & The Virtual Experiments .................................111
Implementation 1 – Moisture Virtual Experiment ............................111
Implementation 2 – Carbon to Nitrogen Virtual Experiment ..........114
Case Summary .......................................................................118
Case 4 - Big Ideas About Ecosystems Activity ...............................119
Description of Activity .................................................................119
Questions & Big Ideas about Ecosystems Activity .........................122
Argumentation & Big Ideas about Ecosystems Activity ....................125
Case Summary ...........................................................................132
Cross-Case Analysis ..................................................................133
Placement of Activities in Curricular Unit ....................................134
Structure of Activities ................................................................136
Type of Inquiry/Science Content Question ...................................139
Asking Questions & Scientific Argumentation ...............................144
Cross-Case Analysis Summary ...................................................151

V. SUMMARY OF FINDINGS, CONCLUSION, & IMPLICATIONS ..........153
Summary of Findings ..................................................................153
Discussion ................................................................................155
Conclusions .............................................................................160
Strengths & Limitations ...............................................................163
Implications .............................................................................164
Implications for Practice ............................................................164
Implications for Future Research ................................................166

APPENDIX A : IMPLEMENTATION 1 –
MAKING OBSERVATIONS (CARD SORT) ACTIVITY .....................169

APPENDIX B: IMPLEMENTATION 2 –
MAKING OBSERVATIONS (CARD SORT) ACTIVITY .....................172

APPENDIX C: IMPLEMENTATION 1 – WHAT factORS? ACTIVITY ........177

APPENDIX D: IMPLEMENTATION 2 – WHAT factORS? ACTIVITY ........179
LIST OF TABLES

Table 1. Representative studies of student-generated questions in science..........................20
Table 2. Studies that examine student questions and argumentation .................................28
Table 3. Selected activities from the Compost curriculum .................................................37
Table 4. Design changes Implementation 1 & Implementation 2 ....................................... 40
Table 5. School and District demographics .....................................................................44
Table 6. School and District student population .............................................................44
Table 7. Small group demographics .............................................................................45
Table 8. Major question categories ..............................................................................53
Table 9. Argumentation coding framework ....................................................................55
Table 10. Total number of questions posed by group per activity .................................58
Table 11. Distance Matrix ............................................................................................59
Table 12. Questions Asked by Individual Students .......................................................60
Table 13 Major Question Categories ...........................................................................62
Table 14. Inquiry/Science Content question sub-categories & examples .......................65
Table 15. Complexity of instances of argumentation descriptions ..................................67
Table 16. Examples of student Inquiry/Science Content questions in the Making Observations (Card Sort) activity .................................................................71
Table 17. Proposing potential research Verbal questions and examples .........................87
Table 18. Proposing potential research Written questions and examples .......................89
Table 19. I-1 Moisture virtual experiment – Science/Inquiry content questions ...............106
Table 20. I-2 C:N virtual experiment – Seeking clarification/explanation of ideas ..........108
Table 21. I-2 C:N virtual experiment – Seeking input questions ....................................110
Table 22. I-1 Male group’s responses in team journal ....................................................114
Table 23. Big ideas about ecosystem – Inquiry/science content questions …………………124
Table 24. Types and frequencies of questions asked by student during activities …………135
Table 25. Type of Inquiry/science content questions per activity …………………………140
Table 26. Relationship between Inquiry/science content questions & instances of argumentation ……………………………………………………………………………………145
Table 27. Complexity of argumentation across activities ………………………………148
LIST OF FIGURES

Figure 1. Easterday, Lewis, & Gerber (2014) Design Process ............................................. 32
Figure 2. Data analysis plan ..................................................................................................... 36
Figure 3. Implementation 1 video camera placement in classroom ..................................... 47
Figure 4. Implementation 2 video camera placement in classroom ..................................... 49
Figure 5. Timeline of activities ............................................................................................. 50
Figure 6. Think-Collaborate-Share Cycle from Compost curriculum ................................. 69
Figure 7. 30 centimeter card ................................................................................................. 73
Figure 8. Temperature card .................................................................................................. 75
Figure 9. The “20 meter tree” card ....................................................................................... 78
Figure 10. The “white couch” card ....................................................................................... 79
Figure 11. Hardness card ...................................................................................................... 81
Figure 12. Compost virtual experiment ................................................................................ 101
Figure 13. Padlet Wall – Virtual experiments ................................................................. 103
Figure 14. I-1 – Data table Moisture virtual experiment ..................................................... 112
Figure 15. Casual chain – virtual experiment ....................................................................... 115
Figure 16. Padlet Wall – Big Ideas about Ecosystems ....................................................... 120
Figure 17. Implementation 1 Team Journal ......................................................................... 121
Figure 18. Implementation 2 Team Journal ......................................................................... 122
Figure 19. Influence of Activities on Student Questions and Argumentation .................. 134
Figure 20. Description of Skeptic role from Fall compost curriculum .............................. 150
CHAPTER ONE
ASKING QUESTIONS AND ARGUMENTATION: INTRODUCTION AND OVERVIEW

In many science classrooms it is the teacher, not the students, who initiates and participates in the majority of the discourse (Baumfield & Mroz, 2002; Duschl & Osborne, 2002; Newton, Driver, & Osborne, 1999). Teachers rely heavily on lecture and demonstrations to cover the breadth of the curriculum mandated by state standards, leaving the majority of students as passive participants of science. Classroom environments that encourage a single answer to a problem and reinforce the teacher as the authoritative voice are not reflective of authentic scientific practice. These classrooms are reproductive rather than productive in supporting students to engage in authentic disciplinary practice (Engle & Conant, 2002). When teachers dominate scientific discussions in classroom it gives students a false sense of how scientific investigations are conducted by scientists in the field.

Educational research conducted in science classrooms (e.g., Larrain, Freire, & Howe, 2014; Newton et al., 1999) report little to no group discussion and student engagement in scientific practices such as asking questions, providing explanations, and engaging in argument from evidence. The majority of science instruction continues to be dominated by teacher talk (Beyer & Davis, 2008; McNeill, Katsh-Singer, González-Howard, & Loper, 2016), despite an increased importance of student involvement and discourse in science and engineering. The National Research Council (NRC, 2012) released the Next Generation Science Standards (NGSS Lead States, 2013) that established a framework for three-dimensional learning, which includes
science and engineering practices, crosscutting concepts, and disciplinary core ideas. The first dimension of learning emphasizes scientific and engineering practices asserting that students should not only be familiar with scientific practices but also be able to successfully conduct an investigation utilizing the practices (NGSS Lead States, 2013).

The first dimension of learning suggests that in order for students to be successful in science, they need to be able to navigate the different discourses or ways of knowing, doing, talking, reading and writing about science (McNeill, 2011). By having students engage in the different discourses and practices of science, students will be mimicking the collaborative discussions and practices that scientists engage in everyday as they advance scientific knowledge within their community. It is the action of working collaboratively with others, the sharing of ideas, constructing scientific arguments, and the questioning of phenomenon that encourages the construction of science knowledge (Barron, 2003; Engle & Conant, 2002). It is not enough for students to merely hear or read expert scientific explanations; students need to engage in and practice scientific skills (Newton et al., 1999). Social interactions between and among students, not teacher-directed lecture, provide the basis for students to begin to construct their scientific understanding (Asterhan & Schwarz, 2009).

Recently in K-12 science education the use of more authentic inquiry activities that promote the development of students’ scientific practices have been on the rise (Kuhn, Arvidsson, Lesperance, & Corprew, 2017). This is in part because the Next Generation Science Standards (NGSS Lead States, 2013) express the need for authentic science learning environments that expose students to scientific practices, like asking questions, planning and carrying out investigations, constructing explanations, and engaging in argumentation. The goal of an authentic science-learning environment is for students to do science and not just do school
(Jiménez-Aleixandre, Rodriguez, & Duschl, 2000). The NGSS states, “students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and its discourses” (NGSS Lead States, 2013, p. 1, Appendix F). Therefore, it is crucial to expose students to and provide them opportunities to utilize scientific practices so students are able to develop their scientific practice, engage in scientific discourses, and ultimately think critically about science concepts.

A lot of attention has been paid to the scientific practice of argumentation, but studies about other scientific practices such as asking questions are much more limited (e.g., Chin & Brown, 2002; Keys, 1998; Marbach-Ad & Sokolove, 2000; Scardamalia & Bereiter, 1992). Even less attention has been paid to how the scientific practices influence each other during scientific inquiry. This study aimed to investigate students’ questions that occurred during four inquiry science activities and the connection between those questions and instances of dialogical argumentation that arose. In the following pages I present a brief rationale for development of students’ scientific practices, specifically focusing on Asking questions and Engaging in arguments with evidence, and why student questioning in conjunction with dialogic argumentation should be studied. A brief overview of the methodology, the significance and limitations of the study are also provided.

**Statement of Problem**

Science practices were included in the NGSS because knowing science content is not enough; students need to be able to use their understanding to investigate the natural world (NGSS Lead States, 2013). The expectation is that students not just know science content but can participate in science exploration and the many discourses of science. By focusing on science practices students are able to move beyond the rote performance of scientific actions and
memorization of scientific facts and instead begin to engage in constructing scientific knowledge (Berland, Schwarz, Krist, & Kenyon, 2016). The scientific practices are also important because when students engage in the practices of science they begin to understand how science knowledge develops and it makes the knowledge more meaningful as students are able to draw connections to their individual worlds (NRC, 2012). The eight practices identified in the NGSS are: 1) Asking questions; 2) Developing and using models; 3) Planning and carrying out investigations; 4) Analyzing and interpreting data; 5) Using mathematics and computational thinking; 6) Constructing explanations; 7) Engaging in argument from evidence; and 8) Obtaining, evaluating, and communicating information.

The identified scientific practices intentionally overlap one another and are interconnected (NGSS Lead States, 2013). The scientific practices do not operate in isolation, and often lead from one practice to another. For example, the practice of Asking questions could lead to the Planning and carrying out investigation which then leads to Analyzing and interpreting data that requires Using mathematics and computational thinking. The example demonstrates that students utilize multiple scientific practices during well-designed and implemented inquiry. However, little is known about how the scientific practices overlap, specifically how one scientific practice influences another. Studies often focus on students’ development or implementation of a single scientific practice such as developing and using models or engaging in argumentation. Yet, if the scientific practices overlap and lead to one another then as educators and researchers we need insight into these areas in order to better support students as they engage in scientific practices.

The practice of “engaging in arguments from evidence,” or argumentation, is a heavily studied scientific practice (Berland & Hammer, 2012; Kuhn, 2010; Manz, 2014; McNeill, 2011;
Osborne, Erduran, & Simon, 2004). K-12 student engagement in argumentation is often framed in a univariable experiment which only reveals a narrow part of authentic scientific inquiry and does not provide students the necessary context (Kuhn et al., 2017). The lack of context causes the construction of an argument to be interpreted as an isolated event and misconstrues students’ perception of argumentation, and other scientific practices, as a set of isolated procedures, instead of being interconnected to other scientific practices (Kuhn et al., 2017). Therefore scientific practices need to be viewed and implemented as a coherent network of activities that can support learners in building science knowledge (Berland et al., 2016).

The practice of argumentation overlaps with many of the other seven scientific practices. Argumentation is most frequently linked with planning and carrying out investigations and analyzing and interpreting data, as the expectation is that students use their data to construct an argument. One scientific practice that is often not directly linked to argumentation is the Asking of questions. Student questions have the potential to foster discussion and debate (Herrenkohl & Cornelius, 2013); and provide the opportunity to delve deeper into a topic because it encourages students to dwell and elaborate on a topic, as well as connect their ideas (Hogan, Nastasi, & Pressley, 1999). All of these are important aspects of developing strong claims with evidential support and justification.

Asking questions and being inquisitive of surroundings is a part of human nature and natural curiosity (Chin & Osborne, 2010a); thus, asking questions is an important scientific practice and cognitive strategy that is at the heart of scientific inquiry, literacy, and learning (Chin & Brown, 2002; Chin & Osborne, 2008; King, 1994). Asking questions provides students the opportunity to articulate their current understanding of a phenomenon, make connections with other ideas, and finally, become aware of what they do or do not know (Chin & Osborne,
Asking questions is also a key discursive move that is important for building student conceptual understanding (Hmelo-Silver & Barrows, 2008; Hogan et al., 1999). When students ask questions it indicates that they have been thinking about information presented and they are trying to extend and connect the information to what they already know (Chin & Brown, 2002; Chin & Osborne, 2008; Hogan et al., 1999). Questioning also contributes to the negotiation of understanding among group members because questions drive students to articulate their confusion, and encourage students to be explicit about their understanding (Chin & Osborne, 2010a; Chinn & Clark, 2013). Yet, despite the ability of students’ questions to enhance learning, opportunities for students to generate and explore their own questions are often limited (Chin & Osborne, 2008). In summary, questions are important in the development of scientific conceptual understanding and attention needs to be paid to how questions in collaborative groups influences other scientific practices, particularly argumentation.

**Aim of Study and Research Questions**

This study examines the relationship between questions posed and dialogical arguments constructed by students during collaborative work in small groups. The focus is on questions and dialogical arguments that arose naturally as students’ participated in a collaborative project-based inquiry science curriculum. The following research questions frame this study:

1. How does student questioning relate to their dialogic argument development during collaborative work?
   a. In what way(s) does the number of questions posed within collaborative group work influence student development of dialogic arguments?
   b. How does the type of question posed in small group collaboration influence their dialogic arguments?
c. How does the complexity of student dialogic arguments (claim, evidence, justification) relate to questions posed during collaboration?

**Significance of the study**

This dissertation contributes to the literature of scientific practices specifically by pushing the conversation forward with regard to student-developed questions and student dialogic argumentation that are generated during small group collaboration. The study draws connections between students’ questions and the instances of dialogical argumentation that occurred. It examines how the number and different types of questions influence student engagement in argumentation. Questions are identified as a metacognitive tool that has the potential to broaden (a) student argumentation space, (b) the questioning space (i.e., types, depth, range, and frequency of questions), and (c) the negotiation space (Chin & Osborne, 2010b).

Asking questions is a means to engage students in the process of learning and more research is needed in how questions within collaborative environments engage students in dialogical argumentation which can ultimately lead to stronger scientific understanding. Currently, little research reports on students’ use of questions in collaborative settings, and what successes (or failures) questioning practices have had in these settings. The studies that do exist regarding student-generated questions have focused on questions created by individuals and usually in written form. Other studies (e.g., Chin & Osborne, 2010b) note that there are bodies of literature for the value of questioning for science conceptual understanding and a separate one for argumentation, and there is a need for researchers to explore the interrelationship between the two scientific practices. This dissertation attempts to explore that relationship.
Research Design

This dissertation was a part of a larger Design-Based Research (DBR) project called Bio-sphere: Fostering Deep Learning of complex biology for Building Our Next Generation’s Scientists, which was supported by the National Science Foundation. The Bio-sphere project was a collaborative effort between the University of Wisconsin at Madison and the University of North Carolina at Chapel Hill (UNC-Chapel Hill) that aimed to develop middle school biology curricula focused on sustainability of ecosystems. The UNC-Chapel Hill research team focused on the Compost curriculum and had data from two implementations with one science teacher and two cohorts of his students. Case study design was used to collect data about eight small groups during curriculum implementation. Each group was video and audio recorded during their science class while participating in activities from the Compost curriculum. Each video recording has corresponding field notes collected by one of two graduate researchers during each implementation. Video data, along with other forms of collected data, were used to identify and examine student-generated questions and arguments. Four cases were developed; a cross case analysis of these cases was conducted to present the findings. Directed content analysis was used to construct the case studies which allowed the researcher to respond to the posed research questions.

Limitations

This study focused on a small sample of students and the discourse they engaged in over four activities from a larger curricular unit. The study therefore cannot be generalized to a larger population nor provide a definitive statement about student questions and the instances of argumentation that occurred. Hence, the individual cases may not be examples of typical student groups nor be representative of the larger phenomenon. The findings are, however, meant to shed
light on how (or not) student questions relate to argumentation that occurs between students in small groups as they engaged with four different science activities. The study design of constructing multiple cases does not facilitate assessment of cause and effect. Student discourse in small groups cannot be directly linked to their post-assessment outcomes; therefore this connection will not be made.

**Chapter One Summary and Overview**

In this chapter, I have outlined my argument for the need to study scientific practices in tandem and to explore the relationships that exist between practices, as they are meant to overlap and be interconnected. If the expectation is for students to develop scientific practices within a context then educators and researchers need to know how the practices influence one another. This study uses the development of cases and cross case analysis to explore the questions students posed and the arguments that developed during a project-based, inquiry science curriculum.

The following chapters will provide more details for each specific section. Chapter Two presents an overview of the current and relevant literature and the conceptual framework that undergirds this work. The third chapter addresses the overall research design, outlines the methods employed to gather data, and the rationale behind selecting the methodologies. Chapter Three also includes the methods used to analyze the data. Chapter Four presents the findings of the study in the form of four case studies and a cross-case analysis. Chapter Five summarizes the findings, draws connections to previous literature, makes recommendations for practical implementation within the classroom, and makes suggestions for future research.
Definitions of Terms

There are several terms that need to be defined in order to effectively communicate how the context influenced student questions, argumentation, and collaboration. In education, terminology can accrue many definitions, with slight differences that can influence the interpretation of meaning. Below are several terms that will be used throughout this dissertation; they are defined here and within the text.

**Argument** – An artifact constructed by individuals that often contains a claim, evidence, and justification (Kuhn & Reiser, 2005; McNeill, 2011; Osborne, 2010).

**Argumentation** – The process that individuals participate in, in order to construct an argument (Kuhn & Reiser, 2005; McNeill, 2011; Osborne, 2010).

**Collaboration** – The process of building and maintaining shared conception of a problem, mutually constructing and negotiating understanding (Engle & Conant, 2002; Roschelle, 1992).

**Dialogical Argumentation** – The process of constructing an argument orally that occurs in conversation, typically in a group setting. Additionally, dialogical argumentation is a form of collaborative discourse in which both parties strive to resolve an issue and reach agreement in pursuit of advancing knowledge within their community (Andriessen & Baker, 2014; Evagorou & Osborne, 2013).

**Instances of argumentation** – Any moment that has aspects of the argumentation process present. This does not always result in the formal development of an argument that contains a claim with supporting evidence and justification.

**Discourse** – The different ways individuals engage with science, this includes the ways of knowing, doing, talking, reading, and writing about science (McNeill, 2011).
*External scripts* – Structured collaboration scripts (e.g., texts, graphics, etc.) that provide collaborators with external support for how to collaborate (Fischer, Kollar, Stegmann, & Wecker, 2013). External scripts acts as guides to support individuals who do not have established internal collaboration scripts (Rummel & Spada, 2005; Fischer et al., 2013).

*Internal scripts* – These are individuals’ established collaborative scripts that guide a person’s understanding of and actions in collaboration (Fischer et al., 2013).
CHAPTER TWO

REVIEW OF THE LITERATURE: ARGUMENTATION & ASKING QUESTIONS IN SCIENCE EDUCATION

The Framework for K-12 Science Education (NRC, 2012) identifies scientific practices as the context in which students should learn the disciplinary core ideas of science. The Framework also stresses that student knowledge of science can develop while also strengthening their competency in related science practices (NRC, 2012). As noted in Chapter One, this enables students to not only know science concepts but to be able to actively participate in science. In Chapter Two, the discussion is expanded on the two scientific practices of interest; Asking questions and Engaging in argument from evidence (argumentation). Relevant research regarding the use of these two practices in the classroom will be discussed along with the how the two practices have been studied together. First, the study is situated in the conceptual framework of collaboration. Collaboration is a 21st Century skill (Dede, 2010) and is a fundamental element of the Compost curricular unit.

Conceptual Framework

As noted in Chapter One, students not only need to know science concepts, they also need to be able to participate in the discourses of science. Discourse refers to the use of language to communicate scientific ideas both verbally and in written text. This study focuses on students’ verbal discourse that occurs during inquiry science activities. Language, specifically communication, is at the heart of learning and the scientific discourses (Osborne, 2010). It has
been stated, “there is no science without language” (Hand, Norton-Meier, Gunel, & Akkus, 2016, p. 848). It is through language that we are able to express ideas, communicate with others, and develop science knowledge (Evagorou & Osborne, 2013). The emphasis on language and discourse suggests development of understanding of scientific concepts is not conducted in isolation, but as a collaborative process. Though collaboration is not explicitly named in *A Framework for K-12 Science Education* (NRC, 2012), it is inferred that collaboration is needed to cultivate students’ scientific practices. The NRC *Framework* (2012) acknowledges that the scientific practices reflect the actual practices of professional scientists and engineers; both of which require the ability to collaborate and communicate with others.

For many science education researchers, knowledge is socially negotiated and the objects of science are constructs that the scientific community uses to interpret a particular phenomenon (Driver, Asoko, Leach, Mortimer, and Scott, 1994). This suggests that collaborative discourse is crucial for scientific discoveries, theory development, and the critique and verification of both (Osborne, 2010). The NRC states, “interaction with others is the most cognitively effective way of learning” (2012, p. 73), thus promoting collaboration as an essential element needed in order for students to acquire and use the science practices and construct their understanding of science concepts.

Collaborative settings provide a context for students to engage in and develop their scientific practices because it provides students the opportunity to share their individual understandings, resolve differing perspective through argumentation, provide critiques of other’s ideas, and listen to explanations of others (Barron, 2003). It sets the stage for students to cultivate their conceptual understanding of scientific phenomena. Collaboration is the process during which students build and maintain a shared conception of a problem or task, share their
expertise, monitor the collective understanding, and mutually construct and negotiate knowledge (Roschelle, 1992). Participation in collaboration allows for students to engage in a variety of cognitive and social activities that lead to a shared understanding of a phenomenon (Miyake & Kirschner, 2014). Thus, working collaboratively with others provides a platform for students to develop their scientific practices such as argumentation and asking questions.

**Scientific Argumentation**

Argumentation is a specific type of discourse and is identified by the National Research Council (2012) as a key scientific practice that demonstrates to students that science is an ever-evolving body of knowledge that is rooted in evidence. The NRC states, “science is replete with arguments that take place both informally, …and formally” (2012, p. 71). Argumentation is a central element to learning science (Osborne et al., 2004) and argumentation entails a fundamental set of skills that are needed in order to be an active participant in scientific discourses (Kuhn, 2010). Science education research has found that not only is argumentation a crucial science practice for students to acquire, it also suggests that participating in argumentation has a positive impact on developing students’ reasoning, critical thinking, and communication skills (Chinn & Clark, 2013; Driver, Newton, & Osborne, 2000; Osborne et al., 2004; Sampson & Clark, 2011, von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

The term ‘argument’ is used by science education researchers to describe the artifact that is generated by students and the term ‘argumentation’ to describe the complex process of generating an argument (Kuhn & Reiser, 2005; Kuhn & Udell, 2003; McNeill, 2011; Osborne, 2010; Osborne et al., 2004; O’Keefe, 1977). As argued above, the scientific practices are not utilized by individuals in isolation but are a means of communication between and among scientists. When argumentation takes place in a group it is referred to as dialogic argumentation.
or collaborative argumentation, which is a form of collaborative discourse in which both parties strive to resolve an issue and reach agreement in pursuit of advancing knowledge within their community (Andriessen & Baker, 2014; Evagorou & Osborne, 2013). This suggests that argumentation is an active process, that it is a social activity in which ideas are tested and refined as individuals work to persuade others and make sense of available evidence and counter-evidence (Berland & Reiser, 2009; Chin & Osborne, 2010a; Nielson, 2013; Evagorou & Osborne, 2013). The discourse that students participate in during a science activity is essential for idea generation, idea improvement and conceptual understanding (Hsu, Chiu, Lin, & Wang, 2015; Nussbaum, 2008).

Several aspects of collaborative argumentation such as asking questions for clarification (Chin & Osborne, 2010a), coordinating evidence with claims (Chinn & Clark, 2013; Kuhn, 2010), as well as proposing, critiquing, and evaluating ideas (Berland & Reiser, 2009; Berland & Lee, 2012) encourages deeper discussions and aids students’ knowledge building of science concepts. This makes collaborative argumentation not just a way to actively learn science, but supports students’ overall thinking and comprehension (Chinn & Clark, 2013), which is a goal of the scientific practices (NRC, 2012). A second goal is to create critical consumers of science (NRC, 2012); students who can effectively participate in collaborative argumentation by constructing sound arguments are more capable of obtaining this goal (Ford, 2012).

Collaborative argumentation not only urges students to be critical consumers of information, it has also been found to assist in the development of student sense-making. A recent study found that when students engaged in the practice of critiquing each others’ ideas it fostered student sense-making and discouraged students from prematurely closing collaborative discussions (Ford, 2012). Being encouraged to critique others’ ideas fosters diversity of thought
within collaborative groups which is important for the constructing of arguments. The
development of sense-making and critiquing of ideas also position students as stakeholders for
their own learning, and gives students agency within the collaborative group and the task (Engle
& Conant, 2002).

Attending to peers’ understanding of science concepts by providing explanations is
another aspect of collaborative argumentation that supports students in building their own
knowledge and understanding (Baker, 2009). It is imperative that students attend to others’ ideas
in collaborative argumentation in order to be successful in accomplishing their goals (Kuhn,
2015). Working collaboratively often leads to students providing elaborate and complex
explanations to peers during group work (Baker, 2009; Coleman, 1998). This is because students
must construct and defend explanations; they have to make sense of the specific science content
they are studying, articulate their understanding, and persuade others that their explanation is
scientifically sound (Berland & Reiser, 2009; Chinn & Clark, 2013). This requires the speaker to
be explicit not only with their explanations, but also with their problem-solving processes. This
can lead to students producing more coherent discourse as well as potentially restructuring their
knowledge (Baker, 2009; diSessa, 2014).

Research focusing on small group collaborative argumentation has reported mixed
findings about the impact collaborative argumentation has had on student conceptual
understanding of science. In one study, students who worked in a collaborative group did not
produce superior arguments compared to individuals who constructed arguments on their own
(Sampson & Clark, 2009). The study focused on students’ written arguments and not on the
students’ discourse during the process of constructing the argument. More recent studies by
Evagorou and Osborne (2013) and Heng, Surif, and Seng (2015) have found that collaborative
groups did produce superior arguments in comparison to students who worked individually. These findings have prompted researchers to continue to examine the benefits of small group collaboration; focusing on the potential learning outcomes concerning student scientific knowledge, as well as the impact on students’ thinking in general.

The scientific practice of argumentation, specifically collaborative or dialogic argumentation, has numerous benefits for the building of science knowledge. The NRC has indicated that argumentation is an essential skill in the pursuit of the production of scientific knowledge. As noted above, argumentation is not only crucial for students’ scientific practice, but it also helps to develop students’ reasoning, critical thinking and communication skills; all of which extend beyond the K-12 science classroom. Finally, argumentation encourages students to be critical consumers of information, by providing a platform for students to ask questions and seek explanations from their peers. Asking questions is another scientific practice that is explored in this dissertation study and is discussed next in this chapter.

**Asking Questions**

Teachers have dominated and continue to control scientific discourse in the classroom. Studies have shown that students need to be active participants in their learning if they are to engage in the different discourses of science (Baumfiled & Mroz, 2002; Duschl & Osborne, 2002; Newton et al., 1999). The scientific practice of *Asking questions* is no different. A typical discursive pattern that has occurred with regards to asking questions in science is: 1) the teacher poses the question to the class; 2) single or multiple students respond to the question; and 3) the teacher evaluates students’ responses. This Initiate, Respond, Evaluate (IRE) pattern (Mehan, 1979) does little to encourage student inquiry and does not introduce students to how science is conducted in real world settings. This type of evaluative pattern leads students to believe that
science is a series of facts and figures to be memorized instead of a discipline inspired by curiosity.

As described above, collaborative discourse between and among students is essential in the development of student understanding of the different discourses of science (McNeill, 2011) and for their construction of science knowledge (Roschelle, 1992). If one of the aims of K-12 science education is to support and encourage students in their development as independent learners and critical thinkers, then encouraging students to ask questions is essential (Woodward, 1992). When students generate their own questions it conveys the message that science is a discipline of inquiry, for which curiosity and questioning are needed as well as encouraged (Chin & Osborne, 2008; Marbach-Ad & Sokolove, 2000). Some argue (e.g., Harper, Etkina, & Lin, 2003; Marbach-Ad & Sokolove, 2000) that questions are the most important part of scientific inquiry, because good questions are what drive inquiry (see Table 1).

An opportunity to ask questions and explore student scientific curiosities encourages the development of students’ scientific habits of mind. Students’ questions stem from an absence or discrepancy in their knowledge or their desire to extend their knowledge (Chin & Osborne, 2008). Asking questions is the first scientific practice described in A Framework for K-12 Science Education (2012). It articulates that students should be able to ask questions of each other, about the scientific texts they read, in relation to phenomena they observe, and regarding conclusions they and their peers draw from models and scientific investigations (NRC, 2012). Asking questions is a key discursive move that supports student understanding of scientific phenomenon, their developing scientific literacy, and helps to make students critical consumers of science (Hmelo-Silver & Barrows, 2008; NRC, 2012). Being able to ask scientific questions is
crucial for investigations and scientific discovery, and it aids students in their collaborative pursuit of science knowledge.
Table 1

**Representative studies of Student-generated Questions in Science**

<table>
<thead>
<tr>
<th>Author &amp; year</th>
<th>Purpose of study</th>
<th>Participants and Setting</th>
<th>Methods/Methodology</th>
<th>Major Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scardamalia &amp; Bereiter (1992)</td>
<td>To examine elementary students' ability to ask and recognize productive questions.</td>
<td>Two self-contained classes of Grade 5-6 students from an inner-city school serving ethnically and socioeconomically heterogeneous population. 1 class served as the treatment group and the other the control.</td>
<td>Experimental design comparing the two classes as they participated in three different activities. Teacher interviews, student-generated questions, classroom observations, and audio recordings of classroom interactions.</td>
<td>There is substantial educational potential in student-generated questions. Under the right conditions, students can produce questions that can direct their inquiry and study of scientific concepts. In a community of learners questions could push against the limits of the current knowledge and would lead to greater construction of knowledge.</td>
</tr>
<tr>
<td>Keys (1998)</td>
<td>To examine reasoning strategies of Year 6 students who had the freedom to generate their own questions for investigation in an everyday classroom setting.</td>
<td>Two classes of Year 6 students. The participating teacher and all students were African American. Students worked in cooperative groups of four and were provided collaborative roles to structure their interactions.</td>
<td>Two student groups were video recorded as they participated in three inquiry investigations. All student-produced work was also collected. The researchers acted as participant observers.</td>
<td>The questions students asked were analyzed and it was found that they posed two different types of questions; Variation questions and Original questions. Variation questions were merely a modified form of a question the teacher presented in an opening lesson. However, students asked more Original questions, novel questions created by the students, than variation questions. This highlights that students are curious and capable of crafting their own inquiry questions.</td>
</tr>
<tr>
<td>Marbach-Ad &amp; Sokolove (2000)</td>
<td>To examine if encouraging students to ask questions in an established active learning environment influences the types of written questions students ask.</td>
<td>400 students enrolled in Biology 100, an introductory biology course.</td>
<td>Student written reflections submitted weekly after class sessions were statistically analyzed.</td>
<td>The norms established in the active learning class encouraged students to ask questions in multiple forms therefore students asked more questions and ultimately asked better questions.</td>
</tr>
<tr>
<td>Chin &amp; Brown (2002)</td>
<td>To investigate how students’ questions help to scaffold learning during the knowledge construction process. Discusses implications of student questioning for science instruction.</td>
<td>6 students from a single class who participated in a 9-week chemistry unit. 1 group of 3 males and 1 group of 3 females.</td>
<td>A case study approach was used to gather data about each student and the groups. Classroom observations, student interviews, video and audio recordings and student work were analyzed to construct the cases.</td>
<td>Student wonderment questions facilitated knowledge construction within the groups. These questions stimulated students to generate explanations and propose solutions to problems. Student questions stimulate group thinking and can reveal the depth of student thinking.</td>
</tr>
</tbody>
</table>
There are many benefits to student engagement in asking questions in collaborative small groups in science. As students participate in the process of asking questions, specifically during argumentation, it broadens the opportunity for student knowledge building (Chin & Osborne, 2010b; Hmelo-silver & Barrows, 2008). Additionally, student questions expressed in small groups are pivotal for the co-construction of knowledge (Hogan et al., 1999). Student questions have been found to prompt students to think more deeply about a concept, dwell on it longer, and provide opportunities to connect ideas (Hogan et al., 1999). Studies have also found that when students ask questions while working in collaborative groups they engage with the content on a deeper level (Barron, 2003) and construct stronger arguments (Evagorou & Osborne, 2013).

Asking questions drives students to articulate their confusion about a topic and encourages them to be explicit about their beliefs, claims, and misconceptions (Chinn & Clark, 2013; Chin & Osborne, 2010a). Questions also enable students to clarify key scientific concepts, make connections between ideas, and challenge opposing viewpoints in addition to providing alternative ideas (Chin & Osborne, 2008, 2010a; Hogan et al., 1999). Asking questions also initiates and helps sustain episodes of knowledge construction during collaborative argumentation (Chin & Osborne, 2010b). The posing of questions enables students to articulate their puzzlement, thus making their thinking visible to all group members (Woodward, 1992; Hogan et al., 1999). Questions also support dialogical argumentation development; student groups who ask more questions have been found to construct better arguments compared to student groups who asked fewer questions (Chin & Osborne, 2010a, 2010b). Several studies found that asking questions supports student reflection on how they and their peers organize newly acquired knowledge (Chin & Osborne, 2010a, 2010b; Herrenkohl & Cornelius, 2013).
Questions also help collaborative groups clarify their findings as well as their own understanding of an observed phenomenon (Herrenkohl & Cornelius, 2013).

Initially, studies regarding asking questions focused on those asked by teachers; it was not until the early 1990s that research transitioned to focus on questions posed by students. One study, conducted by Scardamalia and Bereiter (1992), investigated elementary students’ ability to ask and recognize productive questions. In the study, productive questions posed by students were organized into two broad types: text-based and knowledge-based questions (Scardamalia & Bereiter, 1992). Text-based questions ranged from high-level critical questions to simple queries about unfamiliar words; the root of text-based questions was that the answer could be found within a text. Knowledge-based questions, referred to as wonderment questions, emerge from a student’s deep interest in a topic or from a students’ attempt to make sense of the phenomenon currently under investigation. The researchers found that knowledge-based questions were students’ attempts to extend their knowledge, which was often thought to occur spontaneously (Scardamalia & Bereiter, 1992). Students asked both text-based and knowledge-based questions when they engaged with science content material in collaborative groups; both types of questions were found to be beneficial for student learning (Scardamalia & Bereiter, 1992).

Beyond the identification of the types of questions students ask, other research focused on how students generate questions specifically for inquiry investigations. One study conducted by Keys (1998) found that students generated a variety of inquiry questions after they experienced a teacher-directed exploration. Upon their release to work in small groups, students were instructed to generate their own questions for further investigation about the same science topic. Allowing students to pose their own investigative questions has a profound impact on the direction of classroom instruction. Students’ questions determined the depth and breadth of the
concepts learned, and the scientific processes used during the investigation (Keys, 1998). Of the student-generated questions, 63% were novel while the other 37% were questions identified as variation questions (Keys, 1998). Variation questions were questions that were based upon the demonstration conducted by the teacher with only slight modifications. The findings demonstrate a need for students to be able to ask their own questions and to develop inquiry investigations. Opportunities like these enabled students to gain experience and develop their ability to ask investigable questions.

Others have investigated students’ ability to generate researchable scientific questions. One experimental study consisted of a treatment group, which received instruction on how to write a researchable question, and a control group receiving no instruction (Cuccio-Schirripa & Steiner, 2000). In this study, when achievement in reading, mathematics, and science were controlled, instruction on how to write a researchable question had a statistically significant effect on the level of science question produced by students. Instruction on how to write a high-level researchable science question was an important factor in these students’ ability to generate these types of questions. Student past achievement level did not influence students’ ability to generate researchable questions (Cuccio-Schirripa & Steiner, 2000). Although the two studies conducted by Keys (1998) and Cuccio-Schirripa and Steiner (2000) are methodologically different, both found that students of all achievement levels could generate worthwhile science questions.

K-12 science classrooms are not the only places where asking questions plays an important role in student knowledge construction. Marbach-Ad and Sokolove (2000) conducted a study with two undergraduate entry-level biology courses (approximately 500 students) to examine if undergraduates could be encouraged to ask ‘better’ scientific questions. Students
were enrolled in either a traditional lecture course or an active learning course. The active learning course met as a large class for three, 50-minute sessions per week, and in ten smaller weekly discussion sessions. Students in the active learning course were placed into small collaborative groups and worked with these groups throughout the semester in both the large and small class sessions. Both courses required students to complete five chapter-based homework assignments over the course of the semester. These assignments prompted students to pose questions about the current material being covered in class and served as the data for the study. Over the course of the semester, the active learning students’ progressively asked more and better questions in their homework assignments; whereas the traditional lecture students’ quality and number of questions remained constant over the five homework assignments (Marbach-Ad & Sokolove, 2000). The students in the active learning course also asked significantly more questions during class meetings in comparison to the traditional lecture students (Marbach-Ad & Sokolove, 2000). The norms established in the active learning course were productive in encouraging students to ask questions and helped to support students’ question development.

The above study establishes that the development of classroom norms that foster asking questions is important not only for engaging students in asking scientific questions but also for advancing the quality of those questions. If students are to ask better and more relevant questions then they need opportunities followed by experiences that investigate those questions (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). The teacher cannot be the sole authority in science classrooms; students need to be given agency and authority for their learning (Engle & Conant, 2002). One way to do this is for students to ask and investigate their own scientific questions.

Another study that examined students’ written questions was conducted in a college level introductory physics course. Students were asked to write weekly course reflections specifically
indicating points of confusion and submit them to the course instructors (Harper et al., 2003). The questions students posed in their reflections gave insight into the difficulties the students were experiencing in learning physics. The study found that students who had higher pre-test scores asked more conceptual questions and ultimately had higher post-test scores (Harper et al., 2003). Where students whose questions focused on equations and how to complete assigned problems tended to score lower on both pre- and post-tests (Harper et al., 2003). The study suggests that the questions students ask matter and that high-level conceptual questions indicate that a student is trying to piece together knowledge in a coherent fashion.

Asking questions has been identified as a key strategy that students use to engage in deep learning (Chin & Brown, 2000). Deep learning is characterized as an interpretative process aimed at understanding reality; this is in contrast to learning as memorizing which focuses on discrete individual pieces of knowledge and is associated with a surface approach to learning (Chin & Brown, 2000). Specifically, wonderment type questions are associated with deep learning (Chin & Brown, 2000; Scardamalia & Bereiter, 1992). Wonderment questions reflect students’ curiosity, puzzlement, skepticism, or speculation; these questions are often spontaneous and emerge from a student’s interest in the subject matter (Scardamalia & Bereiter, 1992). Students also ask wonderment questions when they are attempting to relate new and existing knowledge, integrate complex and divergent information, or build associations among different aspects of new information in an effort to understand a new concept (Chin & Brown, 2000). This suggests that students who ask wonderment questions stimulate group conversation, help to advance group knowledge, and activate deeper learning (Chin & Brown, 2000; Scardamalia & Bereiter, 1992). However, just because students utilize a deeper learning approach by using strategies, such as asking questions, this does not mean that students always arrive at
scientifically correct answers. Yet, this approach does stimulate and develop student problem solving skills despite students occasionally arriving at incorrect solutions (Chin & Brown, 2000).

As noted above, wonderment questions have been found to be associated with promoting deep thinking during science. In fact, the highest cognitive thinking and the highest instances of co-construction of knowledge occur during science activities that are open-ended inquiry during which students have the opportunity to ask questions (Chin, 2001). This suggests that the absence of a step-by-step procedure provides students an opportunity to be curious and ask more wonderment questions thus stimulating student talk to occur at a higher cognitive level (Chin, 2001).

However, not all questions stimulate conversation in the same way. There are different types of wonderment questions (comprehension, prediction, anomaly detection, application or cognitive conflict, application, and planning or strategy questions) all of which influence student discourse and the co-construction of knowledge (Chin & Brown, 2002; King, 1994). Students ask more wonderment questions when they attempt to relate new knowledge to their existing knowledge (Chin & Brown, 2002). Students also ask more wonderment questions when they build internal associations between and among new knowledge in their effort to understand science content (Chin & Brown, 2002). Students’ spontaneous wonderment questions during collaboration are also beneficial for co-constructing group knowledge. Wonderment questions have the ability to activate other students’ personal experiences which can then aid the group in co-constructing their understanding of the science concept. The social act of sharing ideas and asking questionings thus has the ability to spark a connection or developing a students’ understanding; ultimately, propelling individual and group learning forward.
In summary, in order for students to view science as something more than a series of facts and figures to be memorized, they need the opportunity to ask questions both about science content and of their peers during scientific investigations. As noted in this literature review, asking questions is an active process that engages students with science content and challenges their current understanding, as well as develops students’ critical thinking skills. Questions that occur spontaneously during collaboration help students to articulate their confusion, which makes student thinking visible; hence supporting students’ co-construction of knowledge. Similar to argumentation, if students are to develop the scientific practice of *Asking questions* they need the opportunity to engage in the activity of asking their own questions.

**Asking Questions and Scientific Argumentation**

Few studies (e.g., Chin & Osborne, 2010a, 2010b; see Table 2) have examined how asking questions and scientific argumentation work together to aid in students’ development of understanding science concepts. One of the few studies that examined these two science practices in tandem found that the more questions that were asked during the inquiry process, the more they influenced the quality of arguments constructed (Chin & Osborne, 2010a). The quality of the questions increased as the number of questions asked increased. More significant, however, was that the type of question mattered more for argument development than just an overall high number of questions (Chin & Osborne, 2010a). Questions that focused on the science concepts were more likely to contribute to students generating elaborate, high quality arguments. Asking questions also helped students work towards a consensus of ideas and helped in resolving opposing views in their collaborative groups (Chin & Osborne, 2010a, 2010b).
Table 2

Studies that Examine Student Questions and Argumentation

| Chin & Osborne (2010a) | The study investigated the potential of students’ written and oral questions both as an epistemic probe and heuristic for initiating collaborative argumentation in science. | 129 Year 7-9 students in Singapore and England. 1 school in each country was coeducational and 1 school was single sex. | Students’ verbal and written questions were analyzed inductively for the kinds of questions posed. | There was a positive and significant correlation between the number of questions and students’ argument score. The more questions students posed about scientific concepts the higher in quality of arguments students produced. Less successful groups asked fewer questions in total and types of questions. |
| Chin & Osborne (2010b) | To examine how student-generated questions can support argumentation in science. | 129 Year 7-9 students in Singapore and England. 1 school in each country was coeducational and 1 school was single sex. | 1 small group in each class (4 groups total) was audiotaped during the collaborative argumentation activity along with all written work. | Productive discourse of successful groups was characterized by 1) questions that focused on key inquiry ideas, 2) explicit and conscious reference to the structure and components of an argument, 3) continual elaboration and expansion of student constructed arguments, and 4) high prevalence of “exploratory talk.” |

Questions have also been used during collaborative talk as a way to challenge a peer’s idea thus encouraging clear articulation of ideas and reasoning which ultimately aids in the development of coherent arguments (Chin and Osborne, 2010b). Students’ questions during collaboration helped to sustain episodes of argumentation that led to the construction of knowledge. Questions also act as epistemic tools that help students by providing structure to the collaborative process which again led students to construct more sophisticated arguments (Chin & Osborne, 2010b).

The current study extends the work of examining how asking questions impact students’ argumentation. As noted above, Chin and Osborne’s (2010a, 2010b) studies found that student-generated questions influence argument development and students’ conceptual understanding.
Both studies utilized multiple scaffolds that aided students in asking questions and generating arguments. Additionally, both studies also utilized the same data set, which was generated in the United Kingdom and Singapore. Therefore, the current study will provide a different context and a fresh perspective in which to examine student-generated questions, and how they influence argumentation.

In this chapter the discussion was expanded about *Engaging in argument from evidence* (argumentation) and *Asking questions*, two of the scientific practices outlined in *The Framework for K-12 Science Education* (NRC, 2012). Both of the scientific practices have been established as important for student engagement in the world of science; and have been studied quite heavily in isolation. However, few studies have examined how the two scientific practices influence one another; this dissertation study attempts to extend the literature in this area. The next chapter describes the methodology used to study the relationship between student-generated questions and their instances of argumentation that occur in small collaborative groups.
CHAPTER THREE
EXAMINING STUDENT QUESTIONS AND ARGUMENTATION: METHODOLOGY

This dissertation study is a part of a larger National Science Foundation (NSF) funded Design-Based Research (DBR) project called Bio-sphere: Fostering Deep learning of Complex Biology for Building Our Next Generation’s Scientist. The Bio-sphere project aimed to develop two collaborative, project-based, technology-supported, inquiry biology curricular units suitable for under-resourced middle schools in rural areas within the United States. This dissertation utilized data collected from the University of North Carolina at Chapel Hill (UNC-Chapel Hill) research site, which includes one school, one science teacher, and two cohorts of his students.

In this methodological chapter the over-arching research approach for the UNC-Chapel Hill site-specific project will be described, along with the specific methodological approach and rationale for data collection for this dissertation. The context of the study along with a description of the participants is provided. Finally, the data analysis plan that was used for the specific dissertation study is outlined.

Research Design

Design-Based Research. The over-arching methodological approach for the larger study was Design Based Research (DBR), an iterative process that simultaneously informs design of educational innovations and develops theory (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Collins, Joseph, & Bielczyc, 2004; Easterday, Lewis, & Gerber, 2014; McKenney & Reeves, 2012). DBR was appropriate for the Bio-sphere project because of its ability to address the
complexity of the natural educational setting of the classroom (Cobb et al., 2003). The curriculum developed by the UNC-Chapel Hill Bio-sphere team, which includes the researcher, was tested in a sixth grade classroom in order to examine how teachers would implement the curriculum to fit the unique context of their classroom. Design-based research studies must operate under the constraint that an effective educational intervention must find its way to the average classroom and be implemented with realistic technology and support (Brown, 1992). The UNC-Chapel Hill Bio-sphere team worked with the participating teacher to adapt the Compost curriculum to fit the teacher’s needs while simultaneously maintaining the integrity of the goals of the curriculum.

DBR is conducted in complex authentic learning environments utilizing a variety of methods to study educational phenomena (McKenney & Reeves, 2012); therefore, both qualitative and quantitative methods were used in order to collect coherent and complete data about the Compost curriculum with regard to learning and instruction. As noted above, DBR is an iterative process that consists of cycles of data collection, analysis and reflection to inform the design of the educational innovation in order to support continuous refinement of theory (Easterday et al., 2014; McKenny & Reeves, 2012). The design process integrates design and scientific methods in order for researchers to generate useful educational products and effective theory.

Easterday and colleagues (2014) designed a model that consists of six iterative phases: focus, understand, define, conceive, build, and test (Figure 1). Each phases enables the researcher/designer to focus on a different aspect of the design and process. In the focus phase, the researcher identifies the stakeholders, the specific problem that will be addressed and the scope of the project along with any constraints along with the scale of the project (Easterday et
al., 2014). The *understand* phase prompts the researcher to investigate the context, gain an understanding of the nature of the problem, and identify any existing solutions that do not work. The *define* phase allows the researcher to set determinate goals to be achieved to solve the identified problem. In the *conceive* phase the researcher sketches a plan for a potential solution to the problem (Easterday et al., 2014). The *build* phase is when researchers construct their conceived design solution. The products generated in this phase may be of low or high fidelity, but they are generated to achieve a specific goal (Easterday et al., 2014). Then in the *test* phase researchers test and evaluate their design solution. The identified phases are not necessarily conducted in a linear sequence; each phase may raise new questions or problems requiring the researcher to transition from phase to phase in an iterative fashion.

*Figure 1. Easterday, Lewis, & Gerber (2014) Design Process.*

This dissertation utilized data collected by the research team at The UNC-Chapel Hill during the 2015-2016 & 2016-2017 school years. The author, Lana Minshew, was a member of the research team that designed the study and collected the data at the research site. The initial study design included examination of the Compost curriculum and the collaborative structures implemented to foster student knowledge construction in collaborative settings. Therefore, the
gathered data would be considered primary data but the analysis will be secondary data analysis due to this dissertation’s research questions being established after data collection had occurred.

The data that was used for this dissertation study was collected during two Test phases. The Test phase allows researchers to evaluate the solution developed during the Conceive and Build phases to their problem that was defined earlier in the design process. The Test phase also provides researchers feedback about the success of their design for their intended practical and theoretical goals (Easterday et al., 2014). Design changes occurred between the two Test phases; those changes will be outlined later in the chapter.

**Case Study Design.** A case study design, according to Stake (2003), is not just a methodological choice but a choice in what is to be studied. A case study should be developed when the focus of a study is to answer ‘why’ or ‘how’ questions about a phenomenon (Baxter & Jack, 2008; Yazan, 2015). Using a case study approach to research facilitates exploration of a phenomenon within its context utilizing a variety of data sources to ensure that all aspects of the phenomenon can be described (Baxter & Jack, 2008).

A case is a bounded system that is complex and contains patterned behavior (Stake, 1995). The bounded system is the criteria a researcher establishes for the development of a case; it indicates both the breadth and the depth of the study (Baxter & Jack, 2008). Case studies are characterized as a process of inquiry about the defined case and the product of that particular inquiry (Stake, 2003). Stake (2003) asserts that the case study should be used to study a particular phenomenon and that close examination of a phenomenon is valuable research. Multiple cases can also be constructed to provide further insight into the phenomenon.

Individual case studies along with multi-case studies can be used as a step toward theory, but they tend to focus on the particulars of a context more than generalization to a broader setting.
(Stake, 2006). One aspect of the larger study conducted at UNC-Chapel Hill was designed to generate data for multiple cases. The vast majority of classroom data collected focused on student interaction during small group collaborative sessions. Eight small groups were video recorded for the duration of the 8-week Compost curriculum implementation, thus providing the research team with valuable data to be able to view the small groups as individual cases. By collecting qualitative and quantitative data continuously for the same groups over an extended period of time the researchers were able to examine how those students participated with the various activities of the curriculum. Thus, providing the research team a view of the individual activities and the curriculum as a whole.

A multiple case study method focuses on the phenomenon of interest of a study, which is the common focus or unique issue of the cases (Stake, 2006). In this dissertation, student-generated questions and collaborative argumentation in small collaborative groups are the phenomenon of interest. Therefore, each of the four selected activities represents a single case that is used to illustrate the phenomenon of student-generated questions within a collaborative argumentation setting (see Figure 2). Multiple case studies allowed the researcher to separately analyze each activity as its own unique entity and then scrutinize the cases holistically and explore the commonalities and differences of questioning and how the questions influence scientific argumentation. Below are the research questions that guided the study of the phenomenon of interest; student-generated questions and collaborative argumentation. Following the research questions, the next section will describe the context of the UNC-Chapel Hill project and outline the data analysis process for developing four cases and a cross case analysis.
Research Questions

1. How does student questioning relate to their dialogic argument development during collaborative work?
   a. In what way(s) does the number of questions posed within collaborative group work influence student development of dialogic arguments?
   b. How does the type of question posed in small group collaboration influence students’ dialogic arguments?
   c. How does the complexity of student dialogic arguments (claim, evidence, justification) relate to questions posed during collaboration?
Figure 2. Data Analysis Plan
Context

Compost curriculum. The Compost curriculum was created by researchers at the University of Wisconsin at Madison and modified by the partners at The University of North Carolina at Chapel Hill. This dissertation focused on the modified curriculum generated at UNC-Chapel Hill. The Compost curriculum is an eight week long, project-based, technology-supported science curriculum. Students build, collect data on, and modify a compost bio-reactor in order to develop compost that decomposes quickly. Students utilize computer simulations to run tests on virtual compost piles and collect secondary inquiry information via an online reference tool. The curriculum consists of several hands-on activities (see Table 3) that provide students with experiences surrounding decomposition, waste, ecosystems, the cycling of matter, and the flow of energy.

Table 3

Selected Activities from the Compost Curriculum

<table>
<thead>
<tr>
<th>Activity Name</th>
<th>Type of Activity</th>
<th>Activity Description</th>
<th>Goals</th>
</tr>
</thead>
</table>
| Make a Compost Bioreactor & Fill it! | Small group, hands-on collaborative activity. | Students work in small groups to build their first compost bioreactor (physical structure and filling with materials for compost) Students will also record their initial observations about their compost bioreactor. | • Students will practice engineering skill of following directions to construct their Bioreactor.  
• Students create a model to make future observations and test out ideas. |
| Making Observations (Card Sort) | Whole class and small group inquiry. | Students work in small groups through a card sorting task and an observation task in order to learn to differentiate between qualitative observations, quantitative observations and inferences. Students will participate in a Think-Collaborate-Share cycle and collaborative norms. | • Students will begin to differentiate between qualitative and quantitative observations.  
• Students will make quantitative and qualitative observations.  
• Students will generate inferences based observations and their own knowledge.  
• Students will begin to connect making observations and inferences to the work they are doing with their bioreactor. |
What Factors help decomposers break down matter?

Whole class and small group inquiry.

In small groups, students brainstorm about the factors that may help decomposers decompose things. Then, the small groups generate questions to guide their VidyaMap exploration on the topic of decomposition. Students are provided question stems to help them compose their research questions.

- Students begin to consider the factors that influence decomposers as organisms and their ability to decompose things in a compost pile.
- Students begin to think about biotic and abiotic factors that influence organisms in ecosystems.
- Students develop secondary inquiry skills through question development and research on VidyaMap.

Virtual Experiment: Moisture Simulation

1 of 4 virtual experiments students experience in their small collaborative groups in the Compost Curriculum.

In small groups, students conduct virtual experiments to gather data on how the moisture in a compost pile affects the rate of decomposition. Students then analyze their data to draw conclusions about how moisture affects the rate of decomposition in compost.

- Students figure out how moisture influences decomposition.
- Students will use data from the virtual experiment to draw conclusions.
- Students will make connections between data they collect and observations they make concerning their bioreactor.

Virtual Experiment: Carbon to Nitrogen Ratio

1 of 4 virtual experiments students experience in their small collaborative groups in the Compost Curriculum.

In small groups, students conduct virtual experiments to gather data on how the Carbon to Nitrogen Ratio affects the rate of decomposition. Students then analyze their data to draw conclusions about how the Carbon to Nitrogen Ratio affects the rate of decomposition in compost.

- Students figure out how the Carbon to Nitrogen Ratio influences decomposition.
- Students will use data from the virtual experiment to draw conclusions.
- Students will make connections between data they collect and observations they make concerning their bioreactor.

Big Ideas about Ecosystems

Whole class and small group inquiry.

Based on other activities in the curriculum, students’ own compost bioreactors, and their research, small groups will summarize what it means for something to be an ecosystem, supporting their claim with evidence.

- Students build an understanding of what constitutes an ecosystem.
- Students make claims and support the claims with evidence.

The complete data set comprised of two implementations of the Compost curriculum resulting in nearly 100 hours of video displaying small group interactions. There were two implementations Spring 2016 and Fall 2016, and four small groups from each implementation (8 in total) were video recorded for select activities that represented a variety and range. However, data were collected for four activities during both implementations (see Table 3 for description.
of each activity): *Making Observations (Card Sort) Activity, What Factors help Decomposers Break Down Matter?, Virtual Simulations: Moisture & Carbon to Nitrogen Ratio, and Big Ideas about Ecosystems*. The analysis process focused on these four activities so that a direct comparison could be made concerning student generated questions and the development of their verbal arguments.

**Collaborative structures.** In the initial design of the UNC-Chapel Hill Compost curriculum, collaborative script theory (Fischer, Kollar, Stegmann, & Wecker, 2013; Kaendler, Weidmann, Rummel, & Spada, 2014) was utilized when designing the small group collaborative activities. Collaborative script theory asserts that there are two types of scripts, internal and external. External scripts are used in order to bolster and develop student internal scripts, which are often missing or lacking (Fischer et al., 2013). External scripts are structural supports that are provided externally and are intended to support individuals during collaborative activities. A few ways that external supports are implemented are via the curriculum, classroom norms, or instructions presented by the teacher. Internal scripts are the collaborative abilities that individuals possess, and influence how they interact with others in collaborative environments.

The UNC-CH team developed a *Think-Collaborate-Share* (TCS) script to support group collaboration. The TCS script provides students with individual thinking time, time to share their ideas with their small group, and then an opportunity to discuss with the whole class. The TCS script was embedded into the Compost curriculum via icons that instructed students on what phase of the TCS they were in; and the implementing teacher also supported this, verbally.

**Design changes.** Due to DBR’s iterative cycle there were slight modifications made to the Compost curriculum and how it was implemented from Spring 2016 to Fall 2016. Design changes were made to various aspects of the curriculum. However, since the focus of this
dissertation is on the small group collaborative setting, only the changes that directly influenced small group collaboration are described. The design changes employed from Implementation 1 (I-1) to Implementation 2 (I-2) are outlined in Table 4 and are discussed in detail, below.

Table 4

Design Changes Implementation 1 & Implementation 2

<table>
<thead>
<tr>
<th>Spring 2016 Implementation 1</th>
<th>Fall 2016 Implementation 2</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborative Roles</td>
<td>Collaborative Roles</td>
<td>Analysis of Implementation 1 data found that students often accepted each other’s responses with little to no discussion. The introduction of the Skeptic role was to encourage students to question their peers and to ask for evidence and reasoning during small group collaboration. The role was designed to facilitate discussion and provide students support in constructing arguments.</td>
</tr>
<tr>
<td>• Discussion Director</td>
<td>• Discussion Director</td>
<td></td>
</tr>
<tr>
<td>• Reporter</td>
<td>• Reporter</td>
<td></td>
</tr>
<tr>
<td>• Starter</td>
<td>• Skeptic</td>
<td></td>
</tr>
<tr>
<td>No Lesson on Collaboration</td>
<td>Lesson on Collaboration</td>
<td>In Implementation 1 the teacher introduced the students to the collaborative roles during the first activity of the Compost curriculum. In order to alleviate students from having to simultaneously think about collaborative structures and the science content, a lesson on how to collaborate with their peers was presented prior to the second implementation in the Fall. Students were exposed to the collaborative roles as well as identifying and establishing collaborative norms they could use during small group work.</td>
</tr>
<tr>
<td>Individual Journals</td>
<td>Team Journals</td>
<td>Analysis revealed that when students each had a journal they spent a lot of time silently writing in the information. To diminish this issue each team had a journal that could be rotated between students.</td>
</tr>
<tr>
<td>• Each student had their own journal to keep track of the team’s progress.</td>
<td>• Each team of three students had one journal to keep track of the team’s progress.</td>
<td></td>
</tr>
</tbody>
</table>

As noted in Table 4, both Implementation 1 and 2 employed collaborative roles as a means to externally support students during collaboration segments. Students in the first
implementation were instructed to take up the roles of Discussion Director, Reporter, and Starter. Students in the second implementation utilized the collaborative roles of Discussion Director and Reporter; however, the Starter role was removed and replaced with the Skeptic. This design change was instituted in order to better support students in facilitating discussions and constructing arguments during their small collaborative segments. Students taking up the Skeptic role were advised to question their peers as well as urge their partners to provide evidence for their thinking. Sample questions like “Why? What is your evidence?” were provided to the whole class during the lesson on collaboration, presented by a member of the research team at the beginning of Implementation 2.

The collaboration lesson was a second design change that influenced the current study. The collaboration lesson provided Implementation 2 students an opportunity to discuss the concept of collaboration, what collaboration should look like in their small groups, and introduced students to the collaborative roles prior to the working with the Compost curriculum. Students in Implementation 1 were introduced to the collaborative roles by their teacher during the Making Observations (Card Sort) activity, which is the first activity after the bioreactor build in the Compost curriculum. Implementation 1 students did not receive any instruction on how to collaborate with each other beyond the introduction of the collaborative roles and instructions that were printed in their Compost Journals.

The final design change was the reduction of individual student journals to team journals. During analysis of Implementation 1, conducted by the UNC-Chapel Hill team, it was found that students often would cease discussing a topic in order to write down information in their individual journals. The individual journals prevented students from collaborating because each student expressed the need to write down information in their own journal, despite the teacher on
numerous occasions stating that only the Reporter needed to write down the group’s data. This caused students to take a task-oriented approach to activities by constantly being focused on filling in their individual journals and completing the designated task. Having multiple journals was also a space issue on student desks; there was not enough room to have three journals and the necessary materials out at one time. The design change of creating team journals was to keep student discussion flowing despite needing to complete tasks within the journal pages and to save space in the classroom.

**Setting.** The larger DBR study takes place in three different states at multiple sites in those states. The specific setting discussed here focuses on the University of North Carolina at Chapel Hill site with the one school, one science teacher, and two cohorts of his students who agreed to participate. The state of North Carolina has 100 counties, of which 80 are classified as rural, making North Carolina a rural/urban state. There are 116 school districts in North Carolina, 100 are county school districts with 16 city districts dispersed throughout the state. This positions the majority of the state’s population as rural and identifies a need to study this setting. The participating school is part of a county school district in the north-central region of North Carolina, serving approximately 6,060 students. All schools in the district, including the focal school, are identified as Title I schools. The participating school was a Science, Technology, Engineering, and Mathematics focused one-to-one technology middle school with approximately 279 students and 14 teachers. The school was identified as a school within a school because it does not have it’s own building. The STEM middle school was situated in an empty wing of one of the districts two high schools.

The participating teacher was the sole sixth grade science teacher and partnered with the research team for two academic years (2015-2016 & 2016-2017). He has been teaching for over
ten years and has been at the STEM focused middle school since its inception over five years ago. The science teacher has a background in physics that he earned in the United Kingdom and is fully licensed to teach science in the state of North Carolina. In North Carolina, sixth grade science is categorized as general science, because of the vast topics that are covered across multiple science disciplines.

**Participants.** Students were from demographically diverse backgrounds; the majority of students were African American, Latina/o, or white (see Table 5 for complete demographic data). The school was identified as a Title I school, indicating that over 40% of the student population qualified for free or reduced lunch (see Table 6). Both cohorts of grade six science students experienced the full Compost curriculum during their regular science instruction.

Students worked in small single-sex, collaborative groups of three for the duration of the implementations. The teacher established the homogenous student groups; he felt as though his students would work best in that environment. One of the goals of the larger DBR study was to investigate student collaboration during small group inquiry. Therefore, four small groups (2 female, 2 male) were purposefully selected by the classroom teacher for deeper study for both implementations (8 groups total). These students were representative of the larger student population both demographically and academically. Students were video and audio recorded as they participated with the Compost curriculum. This study focused on four of the eight focal groups, two groups from each implementation, one female and one male (see Table 7).
### Table 5
**School and District Demographics**

<table>
<thead>
<tr>
<th></th>
<th>African American</th>
<th>Asian</th>
<th>Indian</th>
<th>Latinx</th>
<th>White</th>
<th>Pacific Islander</th>
<th>Bi-racial</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Students</td>
<td>% of the population</td>
<td># of Students</td>
<td>% of the population</td>
<td># of Students</td>
<td>% of the population</td>
<td># of Students</td>
<td>% of the population</td>
</tr>
<tr>
<td>STEM 2015-2016</td>
<td>123</td>
<td>45%</td>
<td>1</td>
<td>&gt;1%</td>
<td>46</td>
<td>17%</td>
<td>86</td>
</tr>
<tr>
<td>STEM 2016-2017</td>
<td>135</td>
<td>48%</td>
<td>2</td>
<td>&gt;1%</td>
<td>51</td>
<td>18%</td>
<td>75</td>
</tr>
<tr>
<td>District 2015-2016</td>
<td>3,984</td>
<td>62%</td>
<td>56</td>
<td>1%</td>
<td>880</td>
<td>14%</td>
<td>1,303</td>
</tr>
<tr>
<td>District 2016-2017</td>
<td>3,839</td>
<td>63%</td>
<td>62</td>
<td>1%</td>
<td>835</td>
<td>14%</td>
<td>1,135</td>
</tr>
</tbody>
</table>

*Retrieved from http://apps.schools.nc.gov*

### Table 6
**School and District Student Population**

<table>
<thead>
<tr>
<th></th>
<th>Total Number of Students</th>
<th>Students Receiving Title I Services</th>
<th>Percent of Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM 2015-2016</td>
<td>274</td>
<td>125</td>
<td>48%</td>
</tr>
<tr>
<td>STEM 2016-2017</td>
<td>279</td>
<td>132</td>
<td>49%</td>
</tr>
<tr>
<td>District 2015-2016</td>
<td>6,421</td>
<td>4,055</td>
<td>63%</td>
</tr>
<tr>
<td>District 2016-2017</td>
<td>6,060</td>
<td>4,036</td>
<td>67%</td>
</tr>
</tbody>
</table>
Table 7

Small Group Demographic Information

<table>
<thead>
<tr>
<th></th>
<th>Implementation 1</th>
<th>Implementation 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Spring 2016)</td>
<td>(Fall 2016)</td>
</tr>
<tr>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Alexa – white</td>
<td>Cedric – African American</td>
<td>Charlotte – white</td>
</tr>
<tr>
<td>Bayley - white</td>
<td>Seth – white</td>
<td>Sasha – African American</td>
</tr>
<tr>
<td>Nia – African American</td>
<td>Xavier – African American</td>
<td>Tamina – African American</td>
</tr>
</tbody>
</table>

Data Collection

As noted above, the author was an active participant in the designing, implementing, and collecting of data associated with the Compost curriculum. In this next section a discussion of the procedures used to collect the data in the classroom during the two implementations of the Compost curriculum.

**Video data collection.** The main mode of data collection was through video and audio devices during classroom instruction. Eleven lessons were purposefully selected from the 8-week Compost curriculum demonstrating the range of the activities and to provide an overview of the curriculum. In Implementation 1 two cameras were positioned in the room, one on the whole class and one on a single small group of three students. The teacher wore a lapel microphone that was synced with the whole group camera. The whole group camera had a wide-angle lens and was positioned in the back of the classroom to capture the teacher as he moved about the room. A single row of students to the right of the view screen was positioned off camera due to students not consenting to being filmed. The whole group camera data was not used as a main source of data for analysis of this dissertation study. However, it did serve as a second vantage point of observing the small groups, and was used to clarify data collected from the small group camera.
The small group camera during Implementation 1 was positioned in front of the small group; a table microphone was placed on the table to capture student conversations (See Figure 3). Two members of the research team, including the author, were present for all eleven lessons to capture field notes. The researchers were positioned near the small group and had headphones connected to the camera in order to collect field notes at five-minute increments. Field notes followed both the teacher and students’ actions as they participated with the Compost curriculum, with an emphasis on student interaction. Student journals were collected at the end of each implementation as a record of student work. The teacher used a free collaborative website called Padlet during several activities; screen shots of student work were captured from this website as well. Student pre- and post-assessments on a content exam and a model building exercise were also collected. However, the pre- and post-assessments were not used in the analysis process due to the limited ability of the research questions direct connections to student learning outcomes.
The second implementation followed similar procedures to collect video and audio data with minor differences (Figure 4). During Implementation 1, one small group from the teacher’s four class periods was selected for deeper study. In the second implementation, two small groups from the teacher’s first two class periods (4 groups total) were selected for deeper study. This entailed having two small group cameras running at the same time. Positioning of the cameras followed the same protocol and the same two researchers, including the author, were present to collect field notes at 5-minute increments. A notable difference in field note collection was that the researcher could only focus on one group at a time. Therefore, one group in each class period.
did not have in the moment field notes recorded. Student artifacts were collected during and after the second implementation, such as Padlet walls and student journals. Student pre- and post-assessments were collected, as well, but were not included in the data analysis for reasons stated above.

Purposeful selection of activities was conducted for Implementation 2. As a research team it was decided that we needed to capture several of the same activities along with new activities in the second iteration. Four activities were selected to be common data points for both implementations; this created points of comparison between the two implementations. However, the larger research project utilizes a DBR approach. Therefore, there were changes made to the curriculum and those changes needed to be captured within the data corpus. The new activities captured during Implementation 2 were not necessarily new activities to the curriculum but reflect changes to the design of the curriculum.
Data Analysis

Video selection. Purposeful selection of video data from the larger corpus followed selection guidelines outlined by Derry et al. (2010). The selection of video data for analysis is critical for examining student interaction in collaborative sessions (Derry, Minshew, Barber-Lester, & Duke, 2018). Video data from the Making Observations (Card Sort) Activity, the Moisture and Carbon to Nitrogen Ratio Virtual Experiments, What Factors help decomposers...
break down matter?, and Big Ideas about Ecosystems were used as the main source of data for this study. This data was selected due to its ability to provide direct comparisons between the two implementations. The activities are dispersed throughout the curricular unit, which provided an overview of the entire curriculum. This helped to negate the novelty of the curriculum in earlier activities and provided insight into student collaborative interactions over an extended period of time (8 weeks; Figure 5).

![Timeline of Activities](image)

**Figure 5.** Timeline of Activities

**Identification of student questions.** Initially, videos for each activity and group were viewed with field notes to gain familiarity with the data. Any field notes that were incomplete for Implementation 2 were generated at this time. The initial viewing of video data along with the
field notes helped to serve as guides to key points of interest such as instances of argumentation. Any identified instances of argumentation were documented with a time stamp in the field notes in order to go back and further investigate these instances in more detail at a later time. Once field notes were completed, the four selected activity videos were viewed for a second time with associated transcripts and student questions were documented. The documentation consisted of identifying the activity, the date the activity occurred, the associated time stamp for the question, the question verbatim, the relevant context surrounding the posed question, and finally other notes of importance about the question and the ensuing interaction. After the completion of a video, which was one class period, a memo was written. The memoing process allowed for the author to note interesting findings that occurred in the activity, and to keep track of and refine thinking during the analysis process. These memos proved to be valuable during not only this process, but in the development of codes in the next phase of data analysis.

Once all videos for each group were viewed and questions were documented, the next phase of data analysis commenced. A grounded approach (Charmaz, 2014) was utilized, and open coding was used as a first step for identifying the types of questions students were posing. The author went through the questions that were extracted from the video data set and attempted to identify the types of questions students were asking. To assist in this process and to check the findings, a fellow graduate student, who has science education expertise and no connection to the larger Bio-Sphere project, was recruited to open code a small portion of Implementation 1 Male data set. The graduate student and the author met and discussed how we each coded a small sample (150 questions) and this led to a refinement of the initial codes. The process and the outcomes from the meeting were documented through a memo. From this point forward the
author coded the rest of the data set on her own, generating new codes as new ideas emerged in the different activities.

After coding the entire data set, a second graduate student was recruited to construct inter-rater agreement. The second recruited graduate student also had a strong background in science education and had no connection to the Bio-Sphere project. The recruited graduate student had not been exposed to the data prior to his recruitment for inter-rater agreement. This process was crucial for verification of the codebook. The graduate student used my full codebook and coded 10% of the entire data set. The sample was pulled from all four groups (Implementation 1, Females & Males; Implementation 2, Females & Males) and represented a small portion of the four activities. An 80% inter-rater agreement was achieved without discussion; therefore, further discussion of the coded items was not pursued.

As coding progressed, themes started to emerge among the codes. A constant comparative method (Glaser, 1965) was used to cluster the codes progressively forming more inclusive categories. This process resulted in Five major categories: Inquiry/Science Content Focused Questions, Defining the Task, Materials Focused Questions, Social Questions, and Other. Table 8 displays the five categories and their corresponding percentages for the entire data set. The categories were compared to relevant literature (e.g., Chin & Osborne, 2010b; Scardamalia & Bereiter, 1992) and found that the emergent categories had similarities to the established literature. For example, the category for Inquiry/Science Content Questions was similar to Chin and Osborne’s (2010b) Key Inquiry category and Scardamalia and Bereiter’s (1992) Knowledge-based questions. All three categories encompassed questions that sought explanations about scientific content, reflected student puzzlement, and students’ overall wondering about science information.
Table 8

**Major Question Categories**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry/Science Content Questions</td>
<td>Questions that seek explanations about scientific content, reflect student puzzlement about science content, and their overall wonderings about science.</td>
</tr>
<tr>
<td>Defining the Task</td>
<td>Questions that focus on what the student or group should be doing. Students try to figure out what should be happening.</td>
</tr>
<tr>
<td>Materials Focused Questions</td>
<td>Question is about the materials needed to complete the task. For example, questions about the team journal, questions posed within the journal, student laptops, bio-reactor, or any other material that the students use during the activity.</td>
</tr>
<tr>
<td>Other</td>
<td>All codes that do not meet the requirements of the other four coding categories.</td>
</tr>
<tr>
<td>Social Questions</td>
<td>Students engage in off topic conversations.</td>
</tr>
</tbody>
</table>

**Identification of instances of argumentation.** Once the coding process for the types of questions students generated was complete students’ instances of argumentation became the focus of analysis. Field notes, videos, memos, and available transcripts were used to identify instances of argumentation that occurred among group members. All forms of data were reviewed multiple times in an attempt to identify all instances of argumentation that occurred during the four activities for each group. Instances of argumentation were identified based upon student actions, such as making a claim, asking a question – specifically asking for evidence, and challenging or opposing an already established idea. Once student instances of argumentation were identified they were transcribed, if not previously, and directed content analysis (Hsieh & Shannon, 2005) was used to identify the different aspects of argumentation that were present in each instance.
Discourse is fluid and does not follow a direct pattern, thus making collaborative or dialogical argumentation difficult to assess. Dialogical moves need to be accounted for; and the sequential context is crucial (Neilson, 2013). Many science education researchers use the Toulmin framework (1958) as a means to dissect and analyze student arguments. Toulmin’s framework is composed of core elements of an argument such as claim, warrant, backings, rebuttal, and justification. Science education research has extrapolated Toulmin’s framework to create a model to compare constructed arguments to; however, the model is strict and suggests a linear pattern. Student discourse can be unfocused or shallow resulting in an array of what the Toulmin model would deem ‘incomplete’ arguments such as the presentation of a claim without supporting evidence, justification for the evidence, and a rebuttal. Because of this, recent studies (e.g., Duschl, 2008; Kim & Song, 2005; Nielson, 2010) have found that the Toulmin framework is not the best way to analyze collaborative (dialogic) argumentation and have developed and used alternative models that potentially are a better-fit for collaborative argumentation (Nielson, 2013).

Not every instance of argumentation in this data set represented the construction of a ‘complete argument’ (i.e., contains a claim, evidence, justification, and a counter claim) in accordance with those who have adapted the Toulmin model. In some instances, students presented a claim to their group with no justification or evidence and the group accepted the claim without discussion. Because of this, the analytic framework developed by Chin and Osborne (2010b) was used as a guide to develop a framework that better suited the data. Chin and Osborne (2010b) identified five distinct levels of argument; however, this did not fully capture all of the instances of argumentation that emerged in the data set. Table 9 provides an explanation of the analytic framework for argumentation used for this study.
The developed framework differed from Chin and Osborne (2010b) in that there was a difference between students negating a claim and providing a counter claim. In several instances students simply disagree with each other but do not provide a counter idea in response. The phenomena of simply shutting down another students’ idea but not providing a counter claim spoke to the collaborative process among group members or the lack of it. This was an important...
distinction to be made about the students’ participation in argumentation and needed to be captured.

In this chapter the research approach utilized by the UNC-Chapel Hill research team for the larger Bio-sphere study was outlined. This included how the initial study was designed and how the data collection occurred within the participating classroom. Next, the context of the study was described, including the Compost curricular unit and it’s design changes, the school setting and student participants. Finally, the data analysis plan that was employed was described along with how the four activities were the source of the four case studies. In the next chapter the findings for each of the four activities is presented, including the cross case analysis.
CHAPTER FOUR

STUDENTS’ QUESTIONS AND INSTANCES OF ARGUMENTATION: FINDINGS

In this chapter, the different kinds of questions and instances of argumentation that transpired during the small group Collaborate segments from the four selected activities will be discussed. First, an analytic summary of the types of questions and instances of argumentation generated by the groups, generally, across all four activities will be presented. Next, a discussion of the rationale for and how the four cases were developed. Then, the findings for each of the four activities are presented as individual case studies. Data from the two implementations (I-1 & I-2) were used to illustrate how each activity influenced the types of questions students posed and the complexity or lack thereof in student argumentation. Finally, a cross-case analysis regarding the four cases constructed for the selected activities is provided.

Initial Analysis of Questions and Argumentation

Initial analyses considered the types of questions students posed at the group level. These analyses identified the composition of the types of questions that were characteristic of the group as a whole. By simply examining the number of questions posed by each group it was found that both Female groups asked considerably more questions than the two Male groups. The Implementation 1 (I-1) Female group posed the most questions, totaling 401 over the course of the four selected activities. The Implementation 2 (I-2) Female group was next, having posed 349 questions. They were followed by the I-1 Male group asking 186 questions and the I-2 Male group posing 178 questions (see Table 10). It is important to note that the teacher established
student groups, and decided that they would be homogenous, single-sex groups. The teacher noted that the students would work best in single-gendered groups for the duration of the study.

Table 10

*Total Number of Questions Posed by Group per Activity*

<table>
<thead>
<tr>
<th>Activities</th>
<th>Card Sort</th>
<th>What Factors?</th>
<th>Virtual Experiments</th>
<th>Big Ideas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>I-1 Female</em></td>
<td>101</td>
<td>114</td>
<td>157</td>
<td>29</td>
<td>401</td>
</tr>
<tr>
<td><em>I-1 Male</em></td>
<td>41</td>
<td>66</td>
<td>59</td>
<td>20</td>
<td>186</td>
</tr>
<tr>
<td><em>I-2 Female</em></td>
<td>51</td>
<td>21</td>
<td>198</td>
<td>79</td>
<td>349</td>
</tr>
<tr>
<td><em>I-2 Male</em></td>
<td>23</td>
<td>38</td>
<td>94</td>
<td>23</td>
<td>178</td>
</tr>
</tbody>
</table>

The variation in the number of questions posed across groups led to the calculation of the Euclidean distance in order to quantify the dissimilarity between the groups. The Euclidean distance is the square root of the sum of squares of attribute differences. This statistic takes into account the codes applied to each group document and provides a holistic look at how the groups are similar. Table 11 displays the distances between each of the groups. Smaller numbers indicate that two groups are more similar, while larger numbers indicate more dissimilarity. The findings provide insight about the groups and their experience with the Compost curricular unit. For example, the I-1 Female group was more similar to the I-2 Female group than they were to either of the two male groups. However, as noted in Table 10, the I-1 Female group were the most similar to the I-2 Female group at 67.71, and the I-1 Male group similarity was at 69.71 which is only a 2.00 difference in similarity. This indicates that the I-1 Female group was very similar to both groups. The I-1 Male group, however, was more similar to the I-2 Male group
than their implementation counterparts, the I-1 Female group, indicating that perhaps gender was influential in similarity for the I-1 Male group, more so than implementation. This is in contrast to the I-2 Female group, which was more similar to the I-2 Male group than the I-1 Female group. This suggests that the implementation structure was a greater influence than gender for the I-2 Female group.

Table 11

Distance Matrix

<table>
<thead>
<tr>
<th>Group</th>
<th>I-1 Female</th>
<th>I-1 Male</th>
<th>I-2 Female</th>
<th>I-2 Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1 Female</td>
<td>0</td>
<td>69.71</td>
<td>67.71</td>
<td>89.88</td>
</tr>
<tr>
<td>I-1 Male</td>
<td>69.71</td>
<td>0</td>
<td>77.74</td>
<td>51.73</td>
</tr>
<tr>
<td>I-2 Female</td>
<td>67.71</td>
<td>77.74</td>
<td>0</td>
<td>59.23</td>
</tr>
<tr>
<td>I-2 Male</td>
<td>89.88</td>
<td>51.73</td>
<td>59.23</td>
<td>0</td>
</tr>
</tbody>
</table>

The inconsistencies of Euclidean distance between the four groups encouraged further exploration of other aspects of the data such as, individual students and the activities. The individual students posed various amounts and types of questions during each of the activities. An interesting finding is that in each group there was an individual whom posed more questions than their group mates (see Table 12). These students asked the most questions overall and in each Major Category, this suggests that these students were active members of each group. Examining the data in this manner provided insight into how group discourse emerged, and which individuals were potentially engaged with the activities, the science content, and who was off-task.
Table 12

*Questions Asked by Individual Students*

<table>
<thead>
<tr>
<th>Group</th>
<th>Student</th>
<th>Inquiry/Science Content</th>
<th>Social</th>
<th>Materials Focused</th>
<th>Task Oriented</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1</td>
<td>Female</td>
<td>Alexa</td>
<td>23</td>
<td>45</td>
<td>13</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bayley</td>
<td>47</td>
<td>69</td>
<td>33</td>
<td>38</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nia</td>
<td>22</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>I-1</td>
<td>Male</td>
<td>Cedric</td>
<td>15</td>
<td>12</td>
<td>16</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seth</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Xavier</td>
<td>43</td>
<td>23</td>
<td>17</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>I-2</td>
<td>Female</td>
<td>Charlotte</td>
<td>27</td>
<td>65</td>
<td>24</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sasha</td>
<td>19</td>
<td>36</td>
<td>11</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tamina</td>
<td>18</td>
<td>61</td>
<td>17</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>I-2</td>
<td>Male</td>
<td>Finn</td>
<td>38</td>
<td>12</td>
<td>16</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jey</td>
<td>19</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roman</td>
<td>18</td>
<td>4</td>
<td>14</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

As analysis progressed the Euclidean distance also inspired the examination the activities themselves for patterns involving questions posed and instances of argumentation, not just the groups. This three-tiered approach to data analysis and organization led to the construction of case studies about the four selected activities. Typically, cases are constructed about individuals or groups of individuals. However, the phenomenon of study, student questions and instances of argumentation developed in a unique pattern within and across the four activities offering insight into how the two scientific practices relate to one another. Specifically, the data suggested that the design of each activity played an important role in the types of questions students posed and the complexity of their instances of argumentation. Therefore, cases were constructed about the four activities studied to highlight what occurred within each unique activity. The next section focuses on the broad analysis of the types of questions students asked across all four activities.
followed by a discussion of argumentation generally. The four case studies constructed for the four activities follows.

**Types of Questions.** The next analyses compared the thematic categories of questions across all groups. This provided a sense of what types of questions dominated student talk overall (see Table 13). Students asked more *Social* questions than other types of question, which accounted for 30% of all questions asked, during the four activities. *Social* questions were characterized as off-topic questions that students asked during collaborative work. The second most prevalent type of question was *Inquiry/Science Content* focused questions with just over 25% of the total questions posed falling into this category. These were questions that sought explanations about science concepts, reflected student confusion about science content, and students’ wonderings about science. The final three categories *Defining the Task, Materials Focused Questions, and Other Questions* were 15.4%, 16%, and 12% of questions posed, respectively (See Appendix J for complete list of sub-category questions). Questions about the *Task* reflected student confusion about what they were doing at that moment. The *Materials focused* questions were about the different materials students needed to use to accomplish the assigned task. Finally, the *Other* questions were questions that did not identify with the other major categories but did not reflect a major theme on their own. The percentages of questions in each major category was useful when looking at the overall trends of the data set and was used as a comparison for the individual groups. Each category had sub-categories that further parsed out student questions. The sub-categories for the *Inquiry/Science Content Focused Questions* are of interest for this study and are discussed at length in each case study.
Table 13

Major Question Categories

<table>
<thead>
<tr>
<th>Major Category</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry/Science Content Focused Questions</td>
<td>Questions that seek explanations about scientific content, reflected student puzzlement about science content, and their overall wonderings about science.</td>
<td>25.7%</td>
</tr>
<tr>
<td>Defining the Task</td>
<td>Questions that focus on what the student or group should be doing. Students try to figure out what should be happening.</td>
<td>15.4%</td>
</tr>
<tr>
<td>Materials Focused Questions</td>
<td>Question is about the materials needed to complete the task. For example, questions about the team journal, questions posed within the journal, student laptops, bioreactor, or any other material that the students use during the activity.</td>
<td>16.0%</td>
</tr>
<tr>
<td>Other</td>
<td>All codes that do not meet the requirements of the other four coding categories.</td>
<td>12.2%</td>
</tr>
<tr>
<td>Social Questions</td>
<td>Students engage in off topic conversations.</td>
<td>30.5%</td>
</tr>
</tbody>
</table>

The students were sixth graders therefore some degree of socializing was to be expected. It was encouraging that the Social questions were not the overwhelming majority of the questions posed by the students. Prior studies (e.g., Chin & Osborne, 2010a; 2010b; Scardamalia & Bereiter, 1992) conducted about students’ questioning did not mention students’ Social questions that emerged during student talk. These studies focused solely on students’ inquiry and content-focused questions. Students’ social interactions are important to take notice of particularly when they occur in collaborative settings. Though not the main focus of this study, the Social questions could be useful to curriculum designers. Similar to when students have off
topic conversations, moments where students deviate from the designed task can provide designers feedback on how engaged the students were with the activity.

Overall, just over 30% of questions students posed involved either Defining the Task or were Materials-focused questions (i.e., “What are we doing?” “So, what do we need to find?” “What’s the password?”). These types of questions helped students to orient themselves to the activities and the materials needed to successfully complete the activities. The required materials included the team journals, the students’ laptops, and various virtual programming on the laptops that took time for students to learn how to navigate. Examining the Defining the Task and Materials-focused questions was enlightening when considered within the confines of the specific activities. They provided insight into whether or not students were struggling to understand the curriculum and its necessary materials. Overall, seeing lower percentages of these two types of questions was encouraging because it indicated that students were able to grasp what was required of them with relative ease. The examination of these specific types of questions was also missing from previous literature (e.g., Chin & Osborne, 2010a; 2010b; Scardamalia & Bereiter, 1992) and demonstrates how this study deviates from and supplements those that already exist.

The Other category had the lowest percentage of all the identified major categories because it functioned as a catchall category for things that did not fit with the other major themes. Questions like Asking about Language, Offering help, Seeking help from an authority, Huh?, and Repeating a Question fell into the Other category. Asking about language referred to students asking how to spell or pronounce a specific word. Seeking help from an authority was a phenomenon that needed to be captured but did not fit in the other major themed categories. These questions involved seeking the help from the teacher or the researcher sitting nearby.
Students would pose questions to these authority figures about all aspects of the activities (i.e., content, materials, and the task). Since the focus of the study was to examine students’ questions in their collaborative groups, questions posed to authority figures were excluded from the more specific question categories. However, as these questions were important and helped students navigate the curricular activities therefore they needed to be captured and accounted for within the data set.

Student-posed questions helped the groups to navigate the task, the materials and the science content represented in each activity. The questions that were identified as Inquiry/Science Content focused questions are of particular interest because they often sparked student discussion, indicated points of student confusion, and instigated deeper thinking about science content than did questions in the other four categories. Specifically, Defining the Task, Materials-Focused questions and Other questions often resided at the surface and focused on procedural and logistic aspects of the curriculum and did not invoke deeper engagement with the content. The Inquiry/Science Content questions, in contrast, often pushed students’ thinking and encouraged them to provide their peers with evidence and/or justification for their thinking. These types of questions were also linked to instances of argumentation that students engaged in during the various activities, whereas the other categories were not. Therefore, the focus of the findings in each case study will specifically discuss the Inquiry/Science Content questions with mention to other categories as needed, along with discussion of related instances of argumentation.

Eight sub-categories in the Inquiry/Science Content category emerged during data analysis (see Table 14). These eight sub-categories demonstrate the range of the types of questions students posed when discussing science content. The type of question and the rate at
which students posed questions varied during each activity. Two sub-categories appeared more
frequently than the others: Seeking clarification/explanation of another’s idea and Seeking
affirmation or confirmation of a presented concept. A description and examples of the different
sub-categories are provided in the four case studies.

Table 14
Inquiry/Science Content Question Sub-Categories & Examples

<table>
<thead>
<tr>
<th>Inquiry/Science Content Sub-Categories</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposing potential research</td>
<td>“Where do decomposers get their energy from?” – Nia</td>
</tr>
<tr>
<td>Prompting someone to share their idea</td>
<td>“What do you think an ecosystem has to have?” – Alexa</td>
</tr>
<tr>
<td>Asking for an explanation for an observed phenomena</td>
<td>“Why is the color of the water like this?” - Roman</td>
</tr>
<tr>
<td>Prompting group to extend their thinking</td>
<td>“So, what else can we talk about this decomposition process?” - Xavier</td>
</tr>
<tr>
<td>Seeking clarification/explanation of another student’s idea</td>
<td>“Wait a minute! They don’t have what?” – Bayley</td>
</tr>
<tr>
<td>Asking for evidence</td>
<td>“Yeah, quan…but how do you know?” – Finn</td>
</tr>
<tr>
<td>Seeking affirmation or confirmation of a presented concept</td>
<td>“So Sound, do y’all agree that it is qualitative?” – Charlotte</td>
</tr>
<tr>
<td>Seeking input on a concept</td>
<td>“So what’s y’all think this should be?” – Xavier</td>
</tr>
</tbody>
</table>

Argumentation. Overall, groups engaged in 131 instances of argumentation during the
four selected activities. Instances of argumentation refer to moments where students engaged in
some part of the process of constructing an argument. These moments are of interest because the
students in this study received minimal instruction on the process of argumentation yet had several instances across the four activities. Table 15 illustrates the different instances of argumentation and their varying complexity. All instances of argumentation include the presentation of a claim; from there students engaged in various types and amount of discussion about the presented claim. For example, all of the groups had instances in which they did not engage in discussion about a claim, but simply accepted it (71 of the 131 instances). Other times students engaged in more complex discussions about a claim, for example a claim with supporting evidence, and the presentation of a counter claim with evidence/justification (1 of the 131). All instances of argumentation are of importance for the study because these were spontaneous moments of argumentation that emerged as students worked in collaborative groups.
Table 15
Complexity of Instances of Argumentation Descriptions

<table>
<thead>
<tr>
<th>Coding Symbol</th>
<th>Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Claim</td>
<td>Presentation of a Claim. (No other aspects of argumentation are present)</td>
</tr>
<tr>
<td>CD</td>
<td>Claim &amp; Simple Disagreement</td>
<td>Presentation of a simple Claim plus a simple disagreement such as “no” or “I don’t think so;” the statements negate the claim but do not offer a counter claim.</td>
</tr>
<tr>
<td>CCc</td>
<td>Claim &amp; Counter Claim</td>
<td>Presentation of a Claim and a Counter Claim but no supporting or justification provided for either.</td>
</tr>
<tr>
<td>CE</td>
<td>Claim with Evidence or Justification</td>
<td>Presentation of a Claim with either supporting evidence or justification. (No other aspects of argumentation are present)</td>
</tr>
<tr>
<td>CED</td>
<td>Claim with Evidence or Justification &amp; Simple Disagreement</td>
<td>Presentation of a Claim with either supporting evidence or justification and a simple disagreement.</td>
</tr>
<tr>
<td>CECc</td>
<td>Claim with Evidence or Justification &amp; Counter Claim</td>
<td>Presentation of a Claim with either supporting evidence or justification with a Counter Claim (No supporting evidence or justification presented with the Counter Claim).</td>
</tr>
<tr>
<td>CCcE</td>
<td>Claim &amp; Counter Claim with Evidence or Justification</td>
<td>Presentation of a Claim with a Counter claim and either supporting evidence or justification. (No supporting evidence or justification presented with the initial Claim)</td>
</tr>
<tr>
<td>CECcE</td>
<td>Claim with Evidence or Justification &amp; Counter Claim with Evidence or Justification</td>
<td>Presentation of a Claim with either supporting evidence or justification with a Counter Claim that has supporting evidence or justification.</td>
</tr>
</tbody>
</table>
All instances of argumentation were used in this analysis because students did not receive formal instruction on how to engage in the process of argumentation for the creation of formal arguments. Of the four activities selected for analysis of this study only one, Big Ideas about Ecosystems, instructs students to support their ideas with evidence. However, it does not provide students information on how to accomplish this task (i.e., it does not identify what is good evidence). Implementation Two (I-2) students had slightly more support in constructing arguments. They participated in a separate activity prior to the Compost curriculum that focused on what is collaboration, how to collaborate, and the activity introduced the collaborative roles. Implementation Two (I-2) had the collaborative role of the Skeptic which was designed specifically to get students to question and probe their peers for evidence to support their claims. These limited supports, however, provide students with minimal instruction on how to construct arguments or engage in argumentation.

In the next section individual cases will be presented for the four activities. First, a description of each activity is provided, followed by a discussion of the questions posed during the activity. For reasons discussed above, emphasis was placed on the Inquiry/Science Content focused questions. A discussion of the instances of argumentation that happened during each of the activities was also included.

**Case 1 - Making Observations (Card Sort) Activity**

**Description of activity.** The Compost unit required students to make qualitative and quantitative observations about the compost mixture in their bioreactors and use those observations to generate inferences about the decomposition of organic material. Students needed a strong understanding of not only what qualitative and quantitative observations, and inferences were; but they were also required to generate them on their own. The Making
*Observations (Card Sort)* activity focused on students’ development of these observational and inference skills.

In the *Making Observations (Card Sort)* activity students were provided with definitions of the three concepts (quantitative observations, qualitative observations and inference) and direct examples of each in their team journal. In this study, the participating classroom teacher also spent significant time in each class period going over the three concepts with the whole class prior to introducing the activity. Students were provided a set of cards, each printed with a different observation or inference, along with an organizational chart in their team journal. The teacher followed the Think-Collaborate-Share cycle (T-C-S), which was a part of the structure of the Compost curricular unit (Figure 6).

![Think-Collaborate-Share Cycle](image)

*Figure 6. Think-Collaborate-Share Cycle from Compost curriculum*

The teacher initially had each group disperse the cards evenly to each group member, and then instructed the students to individually sort the cards into three piles: qualitative observations, quantitative observations, and inferences. A timer was used to signal students to
transition from individual thinking to the Collaborate segment where they worked in their groups of three to discuss the categorization of each card. During the Collaborate segment, group members agreed, disagreed, questioned, and/or provided counter thinking as different members of the group identified and categorized the observations and inferences.

It is important to note that the *Making Observations (Card Sort)* activity was one of the more interactive activities in the Compost curricular unit. It is also the first activity in the Compost curriculum; therefore, it is one of the first opportunities that students had to work together during the implementations. The teacher was consistent in how he presented the activity across class periods and implementations (I-1 & I-2). Additionally, students were provided with descriptions of their collaborative roles and the teacher verbally reminded all class periods across both implementations that they should use the collaborative roles when working together. Students, however, were not provided with prompts, sentence starters, or argumentation structures. What is presented next are student-generated questions and instances of argumentation that occurred naturally in this collaborative setting.

**Questioning and the *Making Observations (Card Sort)* activity.** Students were not provided directives about posing questions during the Collaborate segment of *Making Observations (Card Sort)* activity, yet the four groups posed 216 questions during the activity, with a large percentage of the questions (43%) focusing on aspects of *Inquiry/ Science Content*. As noted earlier in this chapter, the *Inquiry/Science Content*-focused questions were of interest because they exposed student confusion, and were often what sparked student discussion about science content. The percentage of *Inquiry/ Science Content* was significantly higher than the next category, *Task Oriented Questions* that occurred only 16% of the time. Questions posed in the *Inquiry/Science Content* category during the *Making Observations (Card Sort)* activity
varied, with the most questions falling into three of the eight sub-categories: *Seeking input on a concept*, *Seeking confirmation of a concept*, and *Asking for Evidence*. A few examples of questions from these areas are provided below in Table 16.

Table 16

*Examples of student Inquiry/Science Content questions in the Making Observations (Card Sort) activity*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Example</th>
<th>Card Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seeking input on a concept</strong></td>
<td>“So what’d y’all think this [holds up a card] should be?” – Xavier</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“What’s descriptive based?” – Bayley</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“I don’t know how this is an observation?” – Roman</td>
<td></td>
</tr>
<tr>
<td><strong>Seeking confirmation of a concept</strong></td>
<td>“So this is words (points to qualitative card) numbers (points to quantitative card)? Words, numbers right? (repeats pointing action)” – Bayley</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Isn’t quantitative a measurement?” – Xavier</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“So Sound, do y’all agree that it is qualitative?” – Charlotte</td>
<td></td>
</tr>
<tr>
<td><strong>Asking for Evidence</strong></td>
<td>“Why?” – Alexa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Why?” – Sasha</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Yeah, quan…but how do you know?” – Finn</td>
<td></td>
</tr>
</tbody>
</table>

*Seeking input on a concept* and *Seeking confirmation of a concept* questions focused on the definitions of the three main ideas of the activity and on individual cards that the students encountered and found puzzling. For example, Bayley prior to sharing her individual stacks of cards with the group, sought confirmation of her understanding of each word. Her attempt to
seek confirmation from her group members occurred after she had previously called the teacher over to the table during the Think segment in order for the teacher to clarify each concept. Xavier also sought the input of his peers when he was seeking confirmation of his understanding of quantitative observation. Xavier was able to articulate his understanding to the group in order for them to confirm or correct his assertion. Bayley and Xavier’s clarifying questions can be contrasted with Finn’s question that sought direct support about a specific card. Finn was able to express uncertainty about the “Long and Muscular” card and brought his quandary to his group mates, allowing them to provide input on its placement. Charlotte also sought confirmation of her idea about a specific card, yet she had already determined that the card was a qualitative observation and was seeking consensus from her group mates.

Other than the description of the Skeptic role, which appears only in the second implementation, no other directives about argumentation were provided to the students. The Skeptic role instructed students to question and probe their group members for evidence to support their claims. In the first implementation, in which the Skeptic role was not in use, simple questions of “Why?” were posed when students disagreed with a group member’s categorization of a card as either a qualitative observation, quantitative observation or an inference. These questions were few (4) and did not occur on a consistent basis. However, in the second implementation, more questions were posed that directly encouraged students to provide evidence for their thinking (14 out of 18). For example, Finn and Roman consistently asked questions like, “How do you know?” and “Are you sure about this one?”. Both boys demonstrated a curiosity in what their peers were thinking, not only during the Making Observations (Card Sort) activity but also consistently throughout the second implementation.
Roman used questions to prod his group mates for evidence, as well. The following is an episode that occurred when Roman questioned Finn about the categorization of a card (Figure 7).

![Figure 7. 30 centimeter card](image)

Finn: Never mind. 30 centimeters. (Places card in the quantitative stack)
Roman: Why do you think it’s on that?
Finn: Because this, this word is quantitative. There’s all numbers. So basically, this is all numbers. I say this is it, but this is inches. It’s numbers. This is length, it’s a number. It’s a it is 40 degrees Celsius outside. That’s a number.

When Finn placed the 30-centimeter card (Figure 7) in the quantitative stack, Roman asked him “Why do you think it is on that?,” inquiring as to why Finn thought the card represented a quantitative observation. The question prompted Finn to provide justification for his thinking along with other examples of quantitative observations. The Asking for Evidence questions illustrate student disagreement and their attempts to get their peers to provide justification or evidence for their thinking. As noted above, occasionally students would express their uncertainty or confusion in hopes that another student could provide the answer, evidence or a counter claim to their thinking.

**Argumentation and the Making Observations (Card Sort) activity.** With regard to instances of argumentation, the Making Observation (Card Sort) activity was unique in that 55% (72 out of a documented 131) of all instances of argumentation occurred during this activity. For three of the groups, this also accounted for the activity with the highest number of instances of argumentation (I-1 Female, I-1 Male, and I-2 Female). The I-2 Male group, in contrast, had more
instances of argumentation during the What Factors activity. For the Making Observations (Card Sort) activity the I-1 Female group engaged in the most instances of argumentation (36); followed by the I-2 Female group (16), the I-1 Male group (13), and finally the I-2 Male group (7). Overall, the number of instances of argumentation for each group tended to be higher or lower in proportion to the total number of questions that the group posed. The I-1 Female group (407) overall asked more questions, followed by the I-2 Female group (349), the I-1 Male group (186), and then the I-2 Male group (178). It is interesting that the order of number of questions posed is the same as the number of instances of argumentation. This finding will be explored more in the Cross-Case analysis portion of this chapter.

**Simple claims.** The action of physically categorizing cards into one of three categories in the Making Observations (Card Sort) activity lends itself to instances of argumentation. The structure of the activity forces students to make a claim about the categorization of the card, thereby, allowing others to evaluate and either confirm or disagree with the claim. Although it is important to note that not all instances of argumentation resulted in the development of complex arguments (See Table 14 for Complexity of argumentation). Many of the instances of argumentation were identified as providing a simple Claim (47 out of 72). Students would present an idea to the group but would not provide justification or evidence to support the claim nor did anyone oppose the idea or provide a counter claim. This was the least complex instance of argumentation that students presented during Collaborate segments. The excerpt below is from the I-1 Female group demonstrating that the group made initial claims about the categorization of the Observation and Inference Cards and achieved rapid group consensus:

Alexa: Okay, so now you do your qualitative ones (cards).
Bayley: That’s the ones you have to describe with words, right?
Alexa: Mm-hmm (affirmative)
Bayley: Behavior
Alexa: Yeah
Bayley: Fuzzy
Nia: Hold on. Wait I gotta
(She was the reporter and was trying to fill in the appropriate space in the group’s journal)
Alexa: Yeah
Nia: Uh-huh (affirmative)  
Go.
Bayley: Shape
Alexa: Yeah

In this episode, Bayley presented her already sorted cards to the group and Alexa and Nia confirmed Bayley’s categorization of the cards. The episode demonstrates that the group seemed to have a firm understanding of the definition of a qualitative observation and could provide pertinent examples of the concept. For this group, more in-depth argumentation was not needed for these specific cards. In fact, the majority of the I-1 Female group’s instances of argumentation were categorized as simple claims during this activity. Additionally, the cards in the episode above were designed to be strict examples of qualitative observations; therefore, the opportunity to engage in argumentation was minimal.

**Increasing complexity of arguments.** Providing simple claims was the most prevalent instance of argumentation that happened during the *Making Observations (Card Sort)* activity. However, other instances of argumentation did occur. In the I-1 Male group, Seth and Xavier engaged in a more complex instance of argumentation, which was characteristic of a claim with evidence and a counter claim with evidence, about the Temperature card (Figure 8).

![Figure 8. Temperature Card](image)
Seth: I think that goes there. Qualitative. Qualitative.
Xavier: No, it’s quantitative.
Seth: Temperature is a quality. It doesn’t say a certain temperature.
Xavier: Yes, it does, right there.
(Points to thermometers pictured on the card.)
You can tell by it, you didn’t look at it.
Seth: But it doesn’t say that.
Xavier: Yes it does. You can see it. Y-yes you can see it, so you can tell what it is. It’s a quant- a quality is describing something. You ain’t descr-
Seth: Yeah, temperature is describing something.
Xavier: It’s not describing words. I know this is quantitative. It’s telling you the height right there
(Points to picture of thermometer)
That’s qua- that’s, that’s, that’s trust me.

Seth presented his claim that the temperature card went into the qualitative stack. Xavier countered that temperature is quantitative and then Seth countered that “Temperature is a quality” specifically because the card did not indicate a certain temperature. Seth interpreted the picture of the thermometer on the card to mean that one couldn’t discern an actual temperature. Xavier countered with his own explanation that you could read the thermometer pictured on the card and that it indicated a certain number therefore it made it a quantitative observation. The boys did not achieve consensus about the categorization of the card; Xavier eventually resorted to telling Seth that he should trust him in order to end the conversation. Nonetheless, each boy attempted to convince the other to change his thinking. Both provided evidence to support their individual claims about whether or not the card labeled “Temperature” was a qualitative or quantitative observation.

Overall, instances of argumentation that included claims and counter claims with justification and evidence only occurred ten times across all groups and activities analyzed. This was the only instance of argumentation at this level of complexity that the I-1 Male group
engaged in; the majority of their instances of argumentation included the statement of a claim and, occasionally, evidential support. More discussion of the differences in complexity of argumentation produced in each activity is reviewed in the cross-case analysis.

Students in the second implementation (I-2) also engaged in instances of argumentation during the Making Observations (Card Sort) Activity. The I-2 Female group, just like the I-1 Female group, had a series of simple claims in which one student presented her categorization of a set of cards for a concept and the other girls evaluated and ultimately agreed with the placement. In the excerpt below Sasha reads the cards out loud and Charlotte writes them in the team journal.

Sasha: Umm…I’m gonna start with inference. I have ‘The girl is smiling, because she must have done well on her test’ (read verbatim from card).
Charlotte: Smiling girl (Writes in team journal)
Sasha: ‘It smells like cookies, so mom must be baking’ (read verbatim from card).
Charlotte: Mom and baking. How do you spell baking? (Sasha shows Charlotte the card, Charlotte laughs) That’s what I thought. I just wanted to make sure.
Sasha: ‘The customer did not finish his meal, he must be full’ (read verbatim from card).
Charlotte: Okay. Must be full.
Sasha: Those are all inferences.
Charlotte: Alright.

The above excerpt was similar to the I-1 Female group’s episode about qualitative observations. The rapid consensus about the categorization of the cards demonstrates that the I-2 Female group could identify inferences with relative ease.

Several of the cards were designed so that students could easily categorize them as qualitative observations, quantitative observations, or inferences. However, other cards were designed to be ambiguous in order to engage students in conversations about the categorization
of the cards and the provided definitions. The I-2 Female group engaged in an extended instance of argumentation about a card that represented both a qualitative and a quantitative observation. The instance occurred when Sasha, Charlotte, and Tamina were initially released to begin the Collaborate segment. The group started by going through Charlotte’s cards. The first card that Charlotte presented to the group was “The 20 meter high tree has no leaves on it” (Figure 9).

![Figure 9. The “20 meter tree” Card](image)

Charlotte: Okay, so ‘the 20 meter high tree. It has no leaves on it.’ Wouldn’t that be inference? Because it it’s too it’s the 20 meter high tree, which would be (trails off)
Tamina: Because you don’t know.
Charlotte: Um, which would be this. [Turns page in team journal to definitions of concepts and points to the quantitative observation definition]
And then it’s (pause) Had no leaves on it. That would be a characteristic [points to qualitative definition].
So wouldn’t it be inference? Because it has both of them.
Sasha: Well
Charlotte: Because it has both of them.
Sasha: Hmm, like
Tamina: Here. ‘The 20 meter tree, the 20 meter high tree has no leaves on it.’ That’s an inference. You know why?
Sasha: Why?
Tamina: Because have you seen the tree? So how would you know?
Sasha: But if it’s (pause) Well if-
Charlotte: Yay or nay?
Tamina: You see it, and like, how would you not see the tree if you like (trails off)
How would you know that it didn’t have leaves on it then?
Charlotte: Yay or nay?
Sasha: Because it’s fall outside.
Charlotte: Yay or nay?
Sasha: But
Charlotte: Yay or nay?
Sasha: Umm
Tamina: Yay
Sasha: Yeah [reluctantly]

Charlotte began the interaction by claiming the card ‘The 20 meter high tree has no leaves on it’ was an inference. She then used the definitions provided in the team journal to develop her justification for claiming the card should be classified as an inference. Charlotte’s actions, however, did not initially convince Sasha that the card should be categorized as an inference. Sasha had a questioning tone when she began to speak which prompted Charlotte to reiterate her point “because it has both of them.” Charlotte’s interjection denied Sasha the opportunity to disagree and present a counter claim. Tamina, on the other hand, agreed instantly with Charlotte’s categorization. Tamina then spent several moments attempting to convince Sasha that the card should be categorized as an inference; however, Tamina used different justification than Charlotte. In the end Sasha relented to Charlotte and Tamina and agreed that ‘The 20 meter high tree has no leaves on it’ was representative of an inference. Sasha’s reluctant agreement is important because ten minutes later another card (Figure 10) that had both a quantitative and qualitative observation on it was presented to the group. The following interaction occurred:

![The white couch has 3 cushions on it.](image)

*Figure 10. The “white couch” card.*

**Charlotte:** ‘The white couch has three cushions on it.’

**Sasha:** Three (pause) Um, wouldn’t that-

**Charlotte:** That would be (pause) That would be this. (points to qualitative column in team journal)

**Sasha:** Okay

**Charlotte:** No!

**Sasha:** Wait, wouldn’t it be this one? (points to the inference column in the team journal)
Because
(Charlotte cuts Sasha off).

Charlotte: Quantity (pause)
No, because that’s the quantity. That’s the quantity, so-

Sasha: Oh. They look the same. Height (presents new card for discussion)

Sasha attempted to apply Charlotte’s reasoning to a new card that had both a qualitative and quantitative observation. However, Sasha was unable to because in this case Charlotte insisted that the card was representative of a quantitative observation. Charlotte did not acknowledge her previous justification, if a card has both a quantitative and qualitative observation presented then the card is an inference. In both interactions, Sasha was denied the opportunity to present her thoughts to the group. In the first episode, Sasha initially disagreed but was unable to present a coherent counter claim to the group; she was rushed into either agreeing or disagreeing with her group mates. The second interaction was an example of a more complex instance of argumentation of a simple claim without justification or evidence but included two counter claims. The increase in complexity of the argumentation from the first example to the second is encouraging. In the second, more complex instance of argumentation, the girls were able to reason through Charlotte’s initial claim and determine that it was incorrect and then both girls provided individual counter statements. Instances like these demonstrate how students participate in knowledge integration and their ability to reason through scientific content. Even though Sasha acquiesced to Charlotte, the episode shows that Sasha was thinking for herself and was not afraid to question her peers when her understanding differed.

The I-2 Male group did not have as many instances of argumentation in the Making Observations (Card Sort) activity when compared to the other three groups. The I-2 Male group engaged in seven argumentative moments, three were the presentation of a simple claim without justification/evidence and two instances were claims with justification/evidence. The other two
instances of argumentation were more complex. The first instance included a claim with evidence/justification and a disagreement; the second instance had a claim with evidence/justification and a counter claim. Below is one of the more complex instances of argumentation that Finn and Roman engaged in during the *Making Observations (Card Sort)* activity (Figure 11).

![Figure 11. Hardness Card](image)

Finn: I’m not sure about all of this.
(Holding the Hardness Test card in his hand)
Actually, I think it is an inference.

Roman: That could also be qualitative.

Finn: Yeah, and an inference.

Roman: Qualitative

Finn: Because everybody, everybody thinks everything’s different. They’re saying things are hard, but they might not be hard or not. Glasses are not hard. I could break them.

Finn initially was unsure about the “Hardness Test Card” and announced his uncertainty about how to classify the card. Eventually, Finn decided that the Hardness Test Card represented an inference. Roman provided the counter claim that the card was a qualitative observation. Finn accepted Roman’s response but continued forward with his assertion that the Hardness Test was an inference. The justification that Finn provided demonstrated his thought process about how he had arrived at his conclusion that the Hardness Test Card represented an inference. Finn’s inquiry into the categorization of the Hardness Test Card led him to engage in two other discussions, one with the researcher sitting nearby and the other with the teacher during the
whole group Share segment of the activity. In both discussions with authority figures, Finn expressed his claim along with his justification each time. The teacher ultimately supported Roman’s initial claim that the Hardness Test Card was a qualitative observation ending the argument.

**Case Summary.** The *Making Observations (Card Sort) Activity* was unique in multiple ways. It was the first collaborative activity students experienced in the curriculum. It immediately followed the bioreactor build, the project-based part of the curricular unit. At that point, the curriculum was new and something the students had not experienced before. The activity was also hands-on; students had a set of cards that they were physically manipulating into three different piles. The Think-Collaborate-Share cycle also encouraged students to generate their own ideas and share them with their group mates. The I-1 students were not instructed on how to probe their peers for answers or how to question each other for justification and evidence to support their thinking. Their questions occurred naturally and show that student curiosity existed and can be harnessed during organized activities to support student learning. The I-2 students were introduced to the collaborative role of the Skeptic that gave them minimal guidance on asking questions and probing for evidence. This difference between the two implementations resulted in the I-2 groups posing more *Asking for Evidence* questions than the I-1 groups.

Students posed the largest percentage of *Inquiry/Science Content* questions during the *Making Observations (Card Sort) activity*. The three most prevalent type of questions posed were *Seeking input on a science concept*, *Seeking confirmation of a science concept*, and *Asking for Evidence*. The design of the activity encouraged these types of questions as students were instructed to sort through their stack of cards that represented qualitative observations,
quantitative observations, and inferences. Student questions helped them to understand the science content and become familiar with examples of each concept. The Asking for Evidence questions were mainly posed by the I-2 students, 14 out of 18, this could be due to the collaborative role of the Skeptic that was introduced in the second implementation at the request of the teacher. The role encouraged students to ask their peers for evidence or justification for their thinking.

The Making Observations (Card Sort) activity also had the highest instances of argumentation compared to the other four activities. However, most of the instances were simple claims and the groups achieved rapid consensus about the categorization of the cards. The design of the cards influenced how students engaged with the categorization process. Rapid consensus was achieved when cards represented single science concepts; however, more complex instances of argumentation happened when the cards were more ambiguous (i.e., The 20 meter high tree has no leaves on it, The white couch has 3 cushions on it).

All four groups did engage in at least one complex moment of argumentation in which they presented justification/evidence and sometimes multiple counter claims. Again, students did not receive direct instruction nor teacher scaffolded support on how to engage in argumentation; all instances of argumentation occurred naturally in the Collaborate segment. The role of the Skeptic is the only exception as it was an external script intended to support students during the collaborate segments of the curriculum. The description for the role of the Skeptic instructs students to “question and probe your group members for better evidence about their claims.” However, students were not privy to what constituted as evidence or a claim. Clarification on these two items should to be included in the curriculum in order to better support students during moments of argumentation. The lack of clarity about evidence, claims, and justification may
have contributed to why students struggled to provide sufficient justification/evidence to support their claims. Yet it is promising that aspects of argumentation were not completely absent from student conversation. Simple design elements, such as cards with both qualitative and quantitative observations can foster student discourse that encourages argumentation. Additionally, with guidance from the teacher and proposed simple, designed external structural supports in the curriculum, the students could potentially provide not only coherent justifications/evidence, but strong, data driven evidence to support their thinking.


**Description of activity.** The *What Factors?* activity also occurred early in the curricular unit, when students had just begun their investigation into decomposers and the process of decomposition. Prior to the *What Factors?* activity, students explored the science concept of decomposers, which were framed as nature’s trash collectors. Students were introduced to what decomposers break down and what role decomposers play in an environment. In the *What Factors?* activity students further explored the process of decomposition and what abiotic and biotic factors influence decomposers during that process. Additionally, the activity was designed for students to begin to make connections between these factors and compost. The *What Factors?* activity was comprised of a series of three individual tasks that spanned over two class periods. The first two tasks occurred on the same day, and the third task was completed on the following school day. In the first task, students brainstormed ideas in order to explore what they thought helped decomposers break down organic matter. This task consisted of a single complete T-C-S cycle. The second task of the *What Factors? Activity* had students use their activated knowledge and newly acquired knowledge from the Share portion of the previous task to generate research questions utilizing question stems that were provided. The goal of the second
task was to prepare students to investigate how and what factors influenced decomposition the following day, through secondary research in the VidyaMap, an e-textbook. In the third task, students investigated their research questions by conducting research in the VidyaMap and recorded their findings in their team journal (see Appendix C & D for journal pages).

This case study focuses on the first two tasks of the What Factors? activity in which students brainstormed potential influential factors and then started to generate their own research questions using question stems. These two activities occurred in the same class period and were recorded during both implementations. The third task was not recorded during the First implementation (I-1) and, therefore, was not included in the analysis. The teacher’s introduction of the What Factors? activity was similar in all class periods across both implementations. The teacher set up the activity by reviewing and discussing the previous day’s topic, which centered on exploring various types of decomposers and their roles in ecosystems. Students were then introduced to the question, “What factors do you think help decomposers in compost break down organic matter?” and were given Think time. Similar to other activities the teacher utilized a timer to segment the different parts of the T-C-S cycle. After a minute of Think time, students transitioned to the Collaborate segment and discussed what factors they thought influenced decomposers and the process of decomposition. Students had roughly five minutes to discuss before they Shared their ideas with the class. Upon wrapping up the whole group Share time, the teacher transitioned the students to generating their own research questions. The teacher spent significant time on discussing the question stems provided in the Team Journal and the expectation that each person in the group needed to generate their own researchable question.

There were a few differences in the design of the journal layout from the first implementation to the second (see Appendix C & D for the activities). In the first
implementation, the students had space in their journal to write down their individual thoughts to the question posed during the Think segment of the activity and a separate space for new ideas presented in the Collaborate segment. Because of these separate spaces, knowledge integration was captured as students incorporated aspects of their peers’ thinking with their own understanding. The I-2 groups only had their single journal and the lines for writing during the Think segment were removed. Four additional probing questions were also added to the activity to help students make connections to their bio-reactors they had built (See Appendix D for questions). The second task of the activity where students generated their own research questions looked the same for both implementations.

**Questioning and the What Factors? Activity.** The two parts of the What Factors? activity produced different discourse among the students. Most of the instances of argumentation occurred in the first part of the activity in which students engaged in a T-C-S cycle about the factors that influence decomposition. However, most of the students’ questions were posed in the second part of the activity, in which students generated research questions. In total, students posed 243 questions during the What Factors? activity. This is the second highest number of questions posed of the four activities examined for this study. The What Factors? activity also had the second highest percentage of Inquiry/Science Content questions overall, with 32% of the questions asked coded into this category. Students asked 77 Inquiry/Science Content questions during the activity, making the Inquiry/Science Content questions the most prominent question type during the What Factors? activity. The other three categories of questions were considerably lower and students asked a similar amount of each question type: Task Oriented (36), Materials Focused Questions (33), and Other (32).
**Inquiry/Science Content-focused questions.** In other activities, students typically did not ask many research-oriented questions, a sub-category in the *Inquiry/Science Content* questions. The *What Factors?* activity was different due to the task requiring students to generate their own research questions; therefore, 21 of the 77 *Inquiry/Science Content* questions were *Proposing potential research*. Student discussion centered on the generation of their research questions and refining what they were going to investigate in the VidyaMap. Table 17 displays examples of the *Potential Research* questions students asked verbally during the second part of the *What Factors?* activity.

Table 17

*Proposing Potential Research Verbal Questions and Examples*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Why do decomposers decompose? – Cedric</td>
</tr>
<tr>
<td></td>
<td>What happened to the things that have got decomposed? – Finn</td>
</tr>
<tr>
<td></td>
<td>How does water help in decomposition? – Alexa</td>
</tr>
<tr>
<td>Proposing Potential Research - Verbal</td>
<td>Where do decomposers get their energy from? – Nia</td>
</tr>
<tr>
<td></td>
<td>What do decomposers decompose? Like, what do they decompose? Like what do they break down? – Xavier</td>
</tr>
<tr>
<td></td>
<td>What is the most common decomposer? – Bayley</td>
</tr>
</tbody>
</table>

Not all of the groups expressed their *Potential Research* questions verbally. The I-2 Female group did not state or discuss any of their research questions verbally among the group. However, they did write their questions down in their team journal. The I-2 Female group took
turns writing down potential research questions in their team journal, each providing two questions. Due to the girls’ lack of discussion, their Team Journal was used to see what questions they planned on investigating. Examples of students’ written research questions are below in Table 18. The other groups also had questions that were written in their journals but were not discussed during the Collaborate segment. The only exception was the I-1 Male group of Xavier, Seth, and Cedric. All five of their research questions were brought up and discussed during the Collaborate segment. The only discrepancy between what the I-1 Male group discussed and what was written was a slight change of the phrasing of one of Xavier’s questions, which changed from “How do abiotic factors help decomposers?” to “What abiotic factors help decomposers the most?”
Table 1

*Proposing Potential Research Written Questions and Examples*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Implementation</th>
<th>Examples – Female Groups</th>
<th>Examples – Male Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Proposing Potential Research or Wonderment question - Written</em></td>
<td>I-1</td>
<td>What is the most common decomposer? - Bayley</td>
<td>What do decomposers break down? – Cedric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Where do decomposers get their energy from? - Nia</td>
<td>Why do decomposers decompose? – Seth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do some decomposers decompose less than 1 week or not? – Alexa</td>
<td>What abiotic factors help decomposers the most? – Xavier</td>
</tr>
<tr>
<td>I-2</td>
<td></td>
<td>How does temperature help in the decomposition of matter? – Charlotte</td>
<td>How does bacteria get into the bottles? – Finn</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What do decomposers do when something is fully broken down? – Sasha</td>
<td>Why is the color of the water like that? – Roman</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Why do decomposers break down dead organisms? - Tamina</td>
<td>Why is there only a little bit of mold in our bioreactor? - Jey</td>
</tr>
</tbody>
</table>

Students also posed numerous questions that were identified as *Seeking clarification/explanation of another’s idea* and *Prompting someone to share their idea*. The three groups that did openly discuss their potential research questions often posed these two types of questions in order to clarify what a peer asked and to get the conversation started. For example, Cedric in the I-1 Male group asked, “What abiotic factors?” when Xavier posed the following research question, “What, how do abiotic factors help decomposers?” Cedric was the Reporter for the class period and was busy writing down the group’s information and needed clarification.
concerning Xavier’s researchable question. An example of a student *Prompting someone to share their idea* occurred when Nia asked Alexa, “What’s your question?” which prompted Alexa to share her research question and continue the girls’ conversation about their future research on decomposition. Similarly, Roman asked Seth, “How about you?” to get Seth to share a potential research question with the group.

Another interesting interaction among group members was the evaluation of students’ potential research questions. As individuals proposed potential research questions to the group, other members often assessed the proposed question before it was written in the group’s journal. The following excerpt is an example of Xavier sharing his potential research question with the group and Cedric evaluating Xavier’s question before he added it to their list.

Xavier: So my question is going to be “how does bacteria help decomposers?”
Cedric: Say what?
Xavier: “How does bacteria help decomposers?” That’s my first question.
Cedric: Bacteria is a decomposer.
Xavier: Oh. Ok. Umm (pause) wait wait wait. What about trashcans?

Xavier knew that bacteria were involved in the process of decomposition, but did not know that bacteria were, in fact, decomposers. Cedric was able to evaluate Xavier’s question and informed him that bacteria were decomposers suggesting that bacteria could not help decomposers. Xavier then used the new piece of information to try to generate a new research question. This time Xavier posed a question about trashcans, which the boys discussed, and ruled as not a viable area of research, they then moved on to a new topic. The process of evaluation occurred at least once in each of the following groups: I-2 Male, I-1 Female and I-1 Male. The I-2 Female group did not have this type of interaction due to the girls simply writing down their individual questions and not discussing what they wrote down with the group.
**Argumentation and the *What Factors?* activity.** The *What Factors?* activity had the second highest number of instances of argumentation of the four activities with 23 instances. The number of instances of argumentation were lower than the *Making Observations-Card Sort* activity, which had 72. The I-1 and I-2 Female groups each had five instances of argumentation while the I-1 Male group had three during the *What Factors?* activity. The I-2 Male group differed from the other three groups in that they had their highest number of instances of argumentation during the *What Factors?* activity with 10. Overall, the complexity of argumentation that the students engaged in varied from group to group in the activity. Some of the groups had very complex instances of argumentation in which students presented claims with justification/evidence along with appropriate counter claims. For example, the I-1 Female group had two instances of argumentation that included a claim with supporting evidence and a counter claim. Whereas other groups, like the I-1 Male group, only presented a few simple claims with justification/evidence but no disagreements or counter claims.

**Lower instances of argumentation.** The I-1 Female group engaged in five instances of argumentation at varying degrees of complexity. All instances of argumentation occurred while the girls were in the Collaborate segment of the first part of the *What Factors?* activity. These instances happened while they responded to the prompt in their team journal: “What factors do you think help decomposers in compost break down matter?” The girls shared their Think time responses with their group mates and then engaged in a discussion about what they should write in the Collaborate box in their journals.

An interesting pattern was that both of the more complex instances of argumentation had counter claims that were in the form of a question. The question motivated the original speaker to provide justification for her thinking, the example below illustrates this phenomena.
Bayley: So I said, that I think decomposers need sunlight for energy, water like to live, and soil for and living as in soil for living environment.
Alexa: Well, what if it’s like fungi or something that doesn’t need sunlight? Does fungi need sunlight?
Bayley: I don’t know. I was just thinking like umm like they need the basic things but if we we wouldn’t die without sunlight but it would make us like for some reason sunlight to me gives us like energy. Cause like when I’m in the dark I get really sleepy.
Alexa: Yeah, but because it [the sun] grows our crops which we need for food.
Bayley: And the decomposers help the crops

The girls engaged in a brief back and forth about Bayley’s written response she generated during the Think segment to the above question. Bayley’s initial statement did not include justification/evidence to support her thinking. Alexa countered Bayley’s claim about decomposers needing sunlight; Alexa was not convinced that decomposers, fungi specifically, needed sunlight to survive. Bayley’s justification, though lacking scientific evidence, showed that she drew upon her prior knowledge of what organisms need to survive, what she referred to as the “basic things.” Bayley goes on to further reason that the decomposers wouldn’t die without sunlight just like humans wouldn’t die, but that sunlight still provided energy because without sunlight she gets sleepy. Though the girls did not reach a scientific solution to what factors help decomposers break down compost, they were able to activate their prior knowledge with regard to what organisms needed to survive. Their inaccuracy was to be expected at this point in the activity since the goal of the first task was to get students thinking about the topic before they wrote their research questions and then conducted their research in VidyaMap.

The second instance of a question being used to initiate the production of evidence/justification occurred a little later in the I-1 Female group’s Collaborate segment. In the following excerpt, Nia questioned Alexa in regards to the inclusion of energy in her statement about factors that help decomposers break down matter.
Alexa: I wrote, so in Collaborate I wrote they [decomposers] need energy, to stay healthy and grow to do their job.
Nia: They need energy?
Alexa: mmmHmm (affirmation). They need energy to stay healthy and do their job.
Nia: Okay. I wrote they need water, soil, air, sunlight.
Alexa: Okay. Umm. Several items, no several things that give them energy is sunlight, water, and oxygen.

Nia’s question initiated Alexa’s repeating of her statement about what decomposers needed. Though this is not a traditional counter claim, the question shows Nia did not accept Alexa’s claim and wanted further explanation. The interaction was also interesting because of how Alexa incorporated Nia’s ideas into her revised statement about what decomposers need for breaking down matter. Alexa maintained her idea that decomposers needed energy to do their job, but she also incorporated Nia’s inclusion of water, air, and sunlight into her explanation. The use of questions in this instance facilitated students building on each other’s knowledge. Though the statement was scientifically inaccurate it demonstrates the way students are able to extend and build upon each other’s ideas. This is more evident in each girls’ journal as their Think segments reflected their individual ideas; whereas, the space for Collaborate reflected the group’s consensus on the topic which incorporated information from all three girls.

The I-1 Male group had the fewest instances of argumentation in the What Factors? activity with three. The group presented simple claims and on one occasion presented a claim with evidence. For example, Cedric provided a claim with evidence when he was asked by Xavier to state the factors that help decomposers break down matter.

Xavier: Say what you think Cedric. So I can write it down.
Cedric: I know that one factors is that they they [decomposers] eat their food and then poop it out and give the soil nutrients. Which is good which is good for plants and to grow more.
After Cedric’s response, Xavier proceeded to copy down what Cedric had said. Xavier asked a few clarifying questions as he wrote in his journal; however, these questions focused on Xavier’s accuracy of Cedric’s statement and did not question the validity of Cedric’s idea. For example, Xavier wanted to clarify if Xavier meant to say poop. When the group’s journals were examined Cedric’s exact phrase was written in each boys’ journal. The I-1 Male group’s lower instances of argumentation during this activity were not surprising; the group was very focused on completing the task during this class period. The timer on the board consumed a lot of Xavier’s focus; he stated frequently how much time the group had left or that they needed to hurry because time was almost up. The focus on completing the task by filling in their journals diminished the group’s in-depth discussion about the science content and potentially thwarted other instances of argumentation.

The I-2 Female group engaged in five instances of argumentation but four of the five were simple claims without justification or evidence. There was only a single instance where a counter claim was provided in response to another student’s claim. The I-2 Female group did, however, have moments where they built upon each other’s claims. Building on an initial claim is a part of the argumentation process, because often when students are grappling with science content for the first time they exclude pertinent information and others help to fill in the additional information. For example, the following interaction occurred when Tamina and Charlotte worked on a sub-question:

Charlotte: What’s the next question?
Tamina: I’m gonna answer this.
Charlotte: Ok. Let me see it though.
Tamina: [read verbatim from team journal] What are decomposers breaking down? How?
Charlotte: Waste! [Tamina gives Charlotte a dirty look]
Oh. Sorry. I’m sorry. Okay but you can write how. So they are decomposing waste and then you can write how.

Tamina: Okay.
Charlotte: Okay. So they
Tamina: Oh so they
Charlotte: They dec [Tamina puts her hand up and stops Charlotte from speaking]
Tamina: They decomposing waste and they do it by eating well yeah eating and getting all the nutrients out of it.

In the above episode Charlotte immediately responded, “Waste!” as the answer to the question. Tamina built on Charlotte’s one word response, provided more information about how decomposers break down waste, which was not offered by Charlotte initially. In order to do so, however, Tamina had to stop Charlotte from speaking several times in order for her to have an opportunity to share her thoughts. Even though the two girls did not engage in an in-depth debate or question the validity of the response to the question, Tamina was able to build off of Charlotte’s knowledge and extend the claim that was presented to the group.

**I-2 Male group, the exception.** The I-2 Male group was the exception to the low instances of argumentation trend presented by the other three groups during the *What Factors?* activity. The I-2 Male group engaged in 10 instances of argumentation, double that of the other groups. The complexity of the instances of argumentation the I-2 Male group engaged in was quite varied. The following example is of the three boys discussing the sub-question included in the I-2 curriculum: “What do they [quantitative measurements] tell you about the decomposition of your compost?” The I-2 Male group each presented their own claims and provided justification/evidence in support of their thinking.

Roman: What do they [quantitative measurements] tell you about the decomposition of your compost? [read question verbatim from journal] How do they tell you about the decomposition?
Jey: What do they tell you about the [trails off]?
Roman: I don’t get it.
Jey: No idea.
Finn: Okay. That means like how is it breaking it down.
Roman: I guess.
Finn: How is it breaking down.
Roman: I mean its going to break down because all of our all of our stuff we put in there is like organic and stuff.
Finn: Well I say it is going to break down because its going to end up rotten out like the umm lettuce is its going to end up rotten. And the um the decomposers that we can’t see like germs. Not germs.
Roman: Bacteria.
Finn: Bacteria, umm, that’s going to um get inside of that little bitty hole there going to get inside of it. That’s going to turn into umm
Roman: Basically, what I think is um it’s going to decompose because its like all we put in there is organic stuff. Organic stuff that can like
Finn: From nature
Roman: Yeah. From nature and not man made like paper.
Jey: I feel like its so that when we put the water in there to moisten it all up to make it easier to decompose. And we put like some I mean its going to get all wet then the decomposers (inaudible).
Roman: Which lettuce did we put on top?
Finn: So the moisture is going to make it break down?
Jey: Yeah, its going to make it easier for them to break down and the decomposers are gonna (inaudible).
Finn: [Nods head yes]

The exchange above illustrates how students were able to engage in complex conversations about scientific content through the sharing of their individual ideas about the topic of decomposition. Although, the students, at this time, do not have a firm grasp of the process of decomposition they are able to share and discuss their current understanding. The discussion was prompted by a sub-question in the team journal, but it was when Finn rephrased the question to focus on how compost breaks down that the conversation shifted. While, the group did not discuss the quantitative measurements as the initial question posed, they were engaged with the broader topic of decomposition. Roman presented the first of three claims about the material being organic, thereby creating the conditions for compost to break down. Finn provided a second claim that introduced the term “rotten” along with the idea of
“decomposers that we can’t see like germs” do the action of breaking down. Roman provided the term bacteria to replace the term germs that Finn used which he readily agreed to the change in terminology. Roman stuck with his idea that the biggest factor for decomposition was the fact that the material was organic. He clarified his thinking after Finn suggested the phrase “from nature.” Roman incorporated Finn’s suggestion and clarified that organic stuff was from nature and different from man made things. In this interaction Jey brought up a third claim about the moisture level in the compost and suggested that the moisture made decomposition easier. Finn asked a clarifying question about Jey’s statement and can be seen in the video nodding his head in agreement when Jey reiterated his prior statement. The exchange is complex in the number of claims presented in a short period of time along with the justification/evidence each student provided for his thinking.

Another instance of argumentation occurred toward the end of the class period. The I-2 Male group had completed both parts of the What Factors? activity and were examining the contents of their bio-reactor.

Roman: Decomposed not decompo wait it’s not decomposed yet!
Finn: Some of it.
Roman: Not really. If it was we’d see soil in there right now.
Finn: The lettuce. The lettuce. [directing Roman to look at the lettuce in the bio-reactor]
Roman: We’d see soil in it right now.
Finn: Ughhh Unnn [shakes head in disagreement]
Roman: If it was decomposed!
Jey: I don’t think so. I don’t think so. Because we would have [gets interrupted]
Roman: He said it was [points to Finn]. Ok if it was decomposed if it was if it was decomposed wouldn’t there be soil in there right now? If it was decomposed.
Jey: Well we need some dirt in there for it to turn into soil.
Finn: Exactly!
As noted earlier, the *What Factors?* activity occurred early in the sequence of the curriculum; therefore, the material had been in the bio-reactors for around two weeks. Roman strongly believed that no decomposition had occurred in the bio-reactor; for him there needed to be soil inside the bio-reactor in order to claim that decomposition had happened. Finn disagreed with Roman, and pointed out the lettuce, which had started to wilt and shrink in size, as evidence for why some of the material was decomposed. Roman wrestled with the notion that something was either decomposed or not, there was not an in-between for him. It can be inferred that at this point in the implementation Roman did not view decomposition as a process that happened over a period of time, but as something that either was or wasn’t. Finn, on the other hand, attempted to make a claim that some of the material was decomposed and cited the lettuce as evidence. However, Roman continued to hold on to the idea that the material was either decomposed or not decomposed and ultimately rejected Finn’s counter claim and evidence. The exchange demonstrates students’ ability to engage in argumentation, providing justification, evidence, and counter claims without structural support. The interaction happened naturally as the boys were looking at their bio-reactor and made observations about the material inside. The *What Factors?* activity did not call for the students to examine their bio-reactor, the boys did this on their own after they had completed the assigned tasks.

**Case Summary.** The *What Factors?* activity and had the second highest number of overall questions posed and the second highest percentage (32%) of the *Inquiry/Science Content* questions of the four activities. Students *Proposing potential research questions,* was significantly higher during this activity than the others; which is not surprising since the goal of the second task was for students to create their own research questions. Students also *Prompted Someone to Share their idea,* which often led to the evaluation of individual ideas and *Seeking
clarification/explanation of another’s idea. The abundance of these two types of questions may have been due to the teacher instructing that each student had to provide at least one researchable question.

Similarly, the instances of argumentation were the second highest of the four activities with 23 instances. Though the number of instances of argumentation was not as high as the Making Observations (Card Sort) activity the students demonstrated their ability to present claims and counter claims along with supporting evidence and justification. Nearly 50% of the instances of the argumentation that occurred included students providing evidence to support their claims. The What Factors? activity had several instances of argumentation where questions were used as a means to get a group mate to provide evidence or an explanation for their thinking. These episodes demonstrate how asking questions and argumentation work in tandem to support student learning of scientific concepts. On several occasions questions were also used to indicate disagreement, and were used to prompt others to provide justification/evidence for their thinking; which led to more complex and stronger arguments.

Case 3 – Virtual Experiments – Moisture and Carbon to Nitrogen Ratio

Description of activity. The process of decomposition takes weeks to generate fully mature compost. In the Compost curricular unit students have the opportunity to watch the full process in real time in their bioreactor. However, in order to learn about what conditions generate ideal compost a learning tool needed to be created that would enable students to experience the process of decomposition in a short amount of time. Virtual simulations were designed as experiments for students to test the rate of decomposition as they manipulated different variables that impact decomposition. Virtual simulations are computer rendered models that enable users to manipulate and experience certain phenomenon in a controlled setting. The
Compost curricular unit had four virtual simulations that were set up as experiments. These experiments provided students the opportunity to run multiple trials in a short amount of time, thus making the slow process of decomposition more manageable in the constraints of the school year. The four virtual experiments each focused on a different variable of the decomposition process in a compost pile; *Particle Size, Carbon to Nitrogen Ratio, Moisture level,* and *Holistic simulation* (see Appendix E & F for journal pages). Herein, these virtual simulations collectively will be referred to as virtual experiments.

Both implementations utilized all four virtual experiments to engage students with the process of decomposition and the factors that influence the rate of decomposition in a compost pile. Video data were collected during the *Moisture* virtual experiment during the first implementation and the *Carbon to Nitrogen Ratio* virtual experiment in the second implementation. The virtual experiments had similar set ups visually on the screen. A container was positioned in the middle of the screen, the variables students could manipulate were on the right hand side of the screen, and the corresponding dependent variables were on the left side of the screen (see Figure 12).
In the *Moisture* virtual experiment students could add varying amounts of greens (Nitrogen), the three types of browns (Carbon), along with extra water (moisture) if they chose. The goal of the *Moisture* virtual experiment was for students to explore what happens to the decomposition rate of compost at varying levels of moisture. The *Carbon to Nitrogen Ratio* virtual experiment was visually similar to the *Moisture* experiment. The goal for the *Carbon to Nitrogen Ratio* virtual experiment was for students to explore the different ratios of greens to the three types of browns involved in composting. Students were provided data tables in the Compost team journals to record their findings for all of the virtual experiments. The team journals helped to facilitate student thinking about the manipulated variables (moisture level and carbon to nitrogen ratio) and the different outputs under study: rate of decomposition, temperature of compost pile, and odor emitted. In order for students to achieve their goal of
finding the ideal Moisture level or Carbon to Nitrogen ratio they needed to have all three outputs expressed at the optimal level.

Both of these virtual experiments were the second experiments in the series of four that the students experienced during their implementation. In the first implementation the virtual experiments were used in the following order: Carbon to Nitrogen Ratio, Moisture, Particle Size, and Holistic. The order of the activities within the Compost curriculum changed between the implementations due to feedback from the teacher and the work conducted by the University of Wisconsin at Madison research team. In the second implementation, the virtual experiments took place in the following order: Particle Size, Carbon to Nitrogen Ratio, Moisture, and Holistic. The Moisture virtual experiment and Carbon to Nitrogen Ratio virtual experiment were the second simulations the students experienced in their respective implementations. Though these virtual experiments tested different aspects of decomposition, the instructions and structure of the activities were similar across all simulations and implementations.

All virtual experiment activities followed the Think-Collaborate-Share cycle; with students beginning each activity by generating an individual prediction about the variable they would be investigating (i.e. Moisture level or Carbon to Nitrogen Ratio). The Collaborate segment had students running multiple trials (6 or more) together in order to find either the optimal moisture level or the ideal ratio for carbon to nitrogen in compost to promote decomposition. A pilot study found that when students utilized multiple technological devices in small groups conversation among group members is hindered (Minshew, Derry, Barber-Lester, Anderson, 2016). These findings led to the design change from the pilot to the first implementation of only having a single device per small group of three students. The teacher instructed all classes and cohorts of students to use one laptop to conduct the virtual experiments
and record their findings in their group’s team journal. Students were to work together to manipulate the virtual experiment and the corresponding variables. In order to prepare for the Share segment, groups were required to create a Padlet note (Figure 13) in order to share their findings with the rest of the class in order to stimulate whole group discussions about the rate of decomposition under certain conditions.

![Figure 13. Padlet Wall – Virtual Experiment](image)

It is important to disclose that the students in the I-2 implementation did not follow the one laptop per group instruction given by the teacher. In the I-2 groups, each student had their own laptop out and were running the virtual experiment individually and recording their findings collectively in their team journal. This was most likely due to the fact that the students received their brand-new laptops the previous week and the excitement of using laptops in school was still abundant. The I-1 students’ laptops were older and had Internet connectivity issues thus making
it difficult for multiple students to run the virtual simulation simultaneously; therefore, they abided by the single laptop per group set up. The difference in the number of laptops used to access the virtual simulation influenced how the groups interacted and discussed their findings. These findings will be discussed below in regards to student questions and instances of argumentation.

**Questions and the Virtual Experiments.** The virtual simulations had the highest number of questions posed out of all of the studied activities. Students posed 509 questions while interacting with the *Moisture* and *Carbon to Nitrogen Ratio* simulations. The breakdown of the types of questions posed is different than previously discussed activities. For example, students posed more *Social* questions than any other type (172), making *Social* inquiries roughly 34% of all questions posed during the virtual experiments. *Social* questions were any question related to an off-topic discussion (i.e., What are you dressing up as for Halloween?). The number of *Social* questions asked during the virtual experiments was almost double those of *Inquiry/Content* type questions, 172 compared to 96. This is a dramatic change from previous activities where students asked more *Inquiry/Content* questions than any other type. The virtual experiments occurred during week five of each implementation. In I-1 week five was after the students returned from spring break and in I-2, week five was right before winter break. Despite the increase in social interactions, all groups did complete each activity in the allotted time by filling in the associated data charts, and corresponding questions as well as creating their Padlet note to share with the class.

*Task Oriented, Materials-focused,* and *Inquiry/Content* questions all had very similar number of questions, with 94, 90, and 96 questions posed respectively. In each of the virtual experiments, students were tasked with finding the ideal range for the variable they were
working with in the virtual experiments. The majority of the Task Oriented questions were centered on this aspect of the task, either clarifying the task or seeking confirmation about the goals of the activity. This was only the second time students had engaged with this type of virtual experiment, which could explain why the Materials-focused questions increased in comparison to the previous activities. Students had to navigate to the virtual experiment website, chose the appropriate experiment to use, and then figure out how to manipulate the experiment. The students were also required to record numerous pieces of data into their team journal, and several of their questions were on clarifying where to record data in the team journal. The Inquiry/Science Content questions comprised of 19% of the questions that students posed during the virtual experiments. Because the data reflects student interactions during two different virtual experiments each experiment will be discussed separately.

**I-1 – Moisture virtual experiment.** The examples below reflect the questions posed while students were working in the Moisture virtual experiment. In this virtual experiment students were able to manipulate how much water they added to the compost pile in one of two ways: by adding extra water to the pile via a virtual faucet and by the amount of greens added to the organic mixture of compostable material. In the I-1 the majority of the Inquiry/Science Content questions posed involved students Seeking clarification/explanation of ideas and Asking for an explanation for an observed phenomena. In fact 22 of the 31 Inquiry/Science Content questions reflected these two sub-categories (examples of these questions are provided in Table 19). Seeking clarification/explanation of ideas refers to questions that students have about information presented to the group by other members. Asking for an explanation for an observed phenomena refers to students seeking help in understanding an aspect of an experiment/scientific phenomena they just viewed.
Table 19

*I-I Virtual Experiment – Moisture Science/Inquiry Content Questions*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seeking clarification/explanation of ideas</strong></td>
<td>“Didn’t we do 39? (39% moisture) And it still said it was fast and ideal.” – Bayley</td>
</tr>
<tr>
<td></td>
<td>“So, no water?” – Bayley</td>
</tr>
<tr>
<td><strong>Asking for an explanation for an observed phenomena</strong></td>
<td>“So everything was basically normal?” – Xavier</td>
</tr>
<tr>
<td></td>
<td>“Hey, what was the umm. What was the smell for number 2?” – Cedric</td>
</tr>
</tbody>
</table>

The two questions posed by Bayley demonstrate the girls’ tendency to *Seek clarification/explanation of ideas*. These examples occurred while the group was conducting their trials and discussing what they would put in the virtual experiment. Bayley was confused as to why they would run a trial without adding water since they were in the Moisture virtual experiment.

Alexa: Don’t put any moisture.
Bayley: So no water?
Alexa: No. Let’s just see.
Bayley: Well then we’re gonna waste our last trial!
Alexa: Uh-uh! We have a bunch more trials.
Bayley: The point of it [virtual experiment] is to put moisture in it.
Alexa: I know but there’s already moisture in it ‘cus you’re adding greens.
Bayley: Oh!

Bayley’s inquiry sparked a discussion between Alexa and Bayley about how moisture got into a compost pile. One goal for the activity was for the groups to find the lowest percent moisture possible for a good rate of decomposition. Hence, Alexa’s desire to run the experiment without any added moisture. Similarly, Bayley sought clarification as to why they were repeating a percentage. Bayley’s question of “didn’t we do 39? And it still said it was fast and ideal” occurred later in the class period after the group had conducted multiple trials and were going
through their data to determine the ideal range of percent moisture in a compost pile. Bayley’s question and reliance on the data the group collected led to a nuanced discussion about the ideal range for percent moisture. Her question encouraged Alexa to direct Bayley to the group’s data to support their need for conducting a trial to test the rate of decomposition with 39% moisture in the compost.

While the I-1 Female group tended to seek clarification for each other’s ideas, the I-1 Male group focused on * Asking for an explanation for an observed phenomena*. The outputs for the virtual experiments provide students with information about the rate of decomposition, the temperature, the odor it emits, and then additional comments about the compost pile. The students needed all three outputs within a certain scope in order for the percent moisture to be considered in the ideal range. Cedric and Xavier’s questions (see Table 19) focused on the accuracy of the data collected from the *Moisture* virtual experiment. Unfortunately, these questions did not elicit explanations from other group members. The boys, however, did rely on their data to inform their decisions about each additional trial they ran in the virtual experiment. Their reliance on previously collected data enabled them to discover the ideal range of percent moisture for decomposition.

**I-2 implementation – Carbon to Nitrogen Ratio virtual experiment.** In the *Carbon to Nitrogen* virtual experiment students manipulated the amount of greens and browns in the virtual experiment. The goal of the virtual experiment was to find the range that resulted in the ideal rate of decomposition of compost. The I-2 groups posed 65 *Inquiry/Science Content* focused questions which is nearly double what the I-1 groups posed during their virtual experiment. The majority of the I-2 groups *Inquiry/Science Content* questions were identified as either *Seeking Clarification/Explanation of ideas* (33 of 65) and *Seeking input on a concept* (21 of 65).
In the virtual experiment the I-2 groups’ *Seeking Clarification/Explanation of ideas* represented very simple questions that tended to elicit one-word responses that did not generate lengthy discussions about the content (see Table 20). The following questions were posed while students worked in the *Carbon to Nitrogen Ratio* simulation.

Table 20

*I-2 C:N Virtual Experiment – Seeking Clarification/Explanation of Ideas*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Seeking Clarification/Explanation of ideas</em></td>
<td>What is this? Brown 2? No, Brown 1? – Finn</td>
</tr>
<tr>
<td></td>
<td>What was the what was the Nitrogen Nitrogen to carbon on this? – Jey</td>
</tr>
<tr>
<td></td>
<td>How many greens you put? – Tamina</td>
</tr>
<tr>
<td></td>
<td>Ok, Brown 3 is what number? – Charlotte</td>
</tr>
</tbody>
</table>

The examples above demonstrate that students sought clarification on what others presented to the group both verbally and through their choices made in the virtual experiment. As noted above, the I-2 groups each had their own laptops out, accessed the virtual experiment individually, and reported their findings to the group. Therefore, the decisions about quantity and type of material to be used in the experiment were individual decisions and not a group decision as was the case with the I-1 groups. The use of individual laptops could explain why the number of *Seeking Clarification/Explanation of ideas* increased from the I-1 to the I-2. The I-1 students were all involved in manipulating the virtual experiments as a group on a single laptop which made most of their conducted trials group decisions. However, the I-2 groups had to decipher their peer’s thinking before they could understand the data that was being presented.
The questions posed by Finn, Jey, Tamina, and Charlotte (see Table 20) attempted to interpret what a group mate put into the virtual experiment so they could ensure that the data was properly recorded. Knowing the inputs was an essential piece of data needed in order to be successful in finding the ideal range of decomposition in the *Carbon to Nitrogen Ratio* virtual experiment. Overall, the students in the two I-2 groups struggled to determine the carbon to nitrogen ratio prior to running the virtual experiment due to the low communication and the isolation of students utilizing multiple laptops. The I-2 students often received one-word responses or a peer pointed to the laptop screen in reply to an inquiry. Students in the I-2 groups did not query each other about why they included the various amounts of greens and browns. This differed from questions asked by Bayley in the I-1 implementation, which prompted Alexa to provide evidence and justification for the amount of moisture she added to the virtual experiment.

However, the I-2 groups did engage in more discussion when they posed *Seeking input on a concept* type questions. These questions differed from *Seeking clarification/explanation of ideas* in that they prompted others to provide definitions or explanations about content that could be found in the team journal (see Table 21). These questions also tended to focus on the organic material that could be added to the virtual compost pile. As part of the *Carbon to Nitrogen Ratio* virtual experiment students had to determine how much (if any) of the different organic material would be added to their virtual compost pile. Students were provided with an explanation of the different types of organic material in the team journal they could reference.
Table 21

*I-2 C:N Virtual Experiment – Seeking Input Questions*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Seeking input on a concept</em></td>
<td>What is wood? Brown 3 or Brown 1? – Finn</td>
</tr>
<tr>
<td></td>
<td>What is Brown 1, Brown 2, Brown 3? – Charlotte</td>
</tr>
</tbody>
</table>

Finn consistently queried his group mates when he was unsure of what materials needed to be used in their next trial. Finn was focused on finding the range of Carbon to Nitrogen ratios that generated ideal decomposing compost, though his first query “What is wood? Brown 3 or Brown 1?” only engaged Jey in conversation for a brief moment. Jey directed Finn to the page in the team journal that had the information Finn needed, after this simple direction the two boys went back to working individually. Roman responded similarly to Finn when Finn attempted to get Roman to work with him on setting up a trial in the virtual experiment. Finn wanted Roman’s input on the material to be included in the virtual experiment, Finn asked, “What do we need? Do we want to add Brown 2? Add paper? Oats? Wheat? Straw?” to which Roman simply replied “Yea.” The use of individual laptops again hindered the communication among the I-2 Male group. Though the I-2 Male group asked more questions during the virtual experiment their discussion about content was not as rich and tended to be brief often only eliciting one-word responses.

The I-2 Female group displayed similar tendencies as their male counterparts during the virtual experiment. Charlotte sought input from her group mates, Tamina and Sasha, but when
they could not provide her with a sufficient response Charlotte sought out the help of the teacher. Charlotte asked her question, “What is Brown 1, Brown 2, Brown 3?” to the group and after a brief silence she raised her hand to obtain the teacher’s attention. The teacher and Charlotte then engaged in a brief conversation about the different types of Browns that could be used in compost and the virtual experiment. Tamina and Sasha were present for the discussion between Charlotte and the teacher but did not provide input nor ask clarifying questions while the teacher was at their table. Charlotte was completely in charge of the interaction, and upon the teacher’s departure from the group Charlotte began manipulating the virtual experiment on her own and did not include her group mates. In summary, even though the I-2 Female and Male groups asked more Inquiry/Science Content questions than the I-1 groups they did not engage in in-depth discussion about the content as demonstrated by these examples. Instead they spent much of their time working in isolation.

**Argumentation and the Virtual Experiments.** The virtual experiments did not elicit as many instances of argumentation as other activities explored in this dissertation study. Both the Moisture and Carbon to Nitrogen Ratio virtual experiments generated 19 instances of argumentation from the four groups. Group participation in argumentation was virtually equal in number across the implementations with the I-1 groups engaging in ten instances and the I-2 groups participating in nine.

**II implementation – Moisture Virtual Experiment.** The I-1 Female group engaged in six instances of argumentation while they worked in the Moisture virtual experiment. Most of the arguments included a claim with either justification or supporting evidence. Many of these instances of argumentation occurred because of the questions in the data table in the team journal (see Figure 14). Students were asked to reflect on the trial they completed and respond to two
questions prior to moving on to the next trial. This set students up to find the ideal rate of decomposition and helped them to be methodical when conducting their trials. In the example below Bayley responds to one of the questions.

![Figure 1.4](image)

<table>
<thead>
<tr>
<th>Independent / Manipulated Variable</th>
<th>Dependent / Responding Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>% Moisture</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>What was the result of trial 1? Was decomposition successful? Explain how you know:</strong></td>
</tr>
<tr>
<td></td>
<td><strong>How could you change the amount of moisture to get a better result? Explain why you think this:</strong></td>
</tr>
</tbody>
</table>

*Figure 14. I-1 – Data table Moisture Virtual Experiment*

Bayley: (Reading from the team journal verbatim) “What was the result of the first trial? Was decomposition sess-successful? Explain how you know.”
Successful because the thingy [virtual experiment] said so.
Successful because our rates were good. The smell was good and the everything was good. The decomposing rate was fast and ideal.

Based on the outputs from the virtual experiment Bayley was able to reason that the trial was successful and used the data as her evidential support. Bayley used the data from the virtual experiment which demonstrated that she understood the question and what it meant by *Explain how you know*. The group did not discuss her response; Alexa simply copied it nearly verbatim into their team journal and the girls moved on to the next trial. Simple agreement is not always a negative during instances of argumentation. Bayley was able to sufficiently support her claim
with the data from the virtual experiment; therefore, an elaborate discussion among the group was not needed.

The I-1 Male group had four instances of argumentation while they interacted with the Moisture virtual experiment. Two of those instances, like with the I-1 Female group, occurred due to the questions in the data table in the team journal, and consisted of claims with either justification or evidence. One of these instances is illustrated below; however, the outcome that emerged differed from the I-1 Female group:

Xavier: (Reading verbatim from the team journal) “What was the result of trial one?”
Cedric: What does it mean by the result of trial 1?
Xavier: Oh, whether is, was it successful? Was it, what we thought it was.
Seth: I’m going to say “no,” because it’s slow and stinky.
Xavier: Yeah.
Seth: (interrupts Xavier) No. I don’t think it was successful.
Xavier: The s-stinkier it would be, or smellier.
Cedric: Okay, so that mean we gotta write this
Xavier: Write what?
Cedric: What you just said.

In the above excerpt Xavier began the conversation by posing a question in order to get clarification about how the group was to respond to the prompt. Cedric was able to clarify what the team journal asked, which prompted Xavier’s initial claim that “Yeah” the trial was successful. Seth countered this claim and stated “No, because it’s (the compost) slow and stinky.” Cedric and Xavier did not verbally acknowledge Seth’s counter claim and evidence. Yet, Xavier’s next statement supported Seth’s counter claim that the trial was not successful. Despite this support, Cedric identified Xavier’s initial claim of “Yeah” as the group’s response to the question. As noted in the Research Design and Methods, each student in the first implementation had their own journal to record their data. In investigating the boys’ Compost Journals I found
that each one wrote that the trial in question was successful (see Table 22). Cedric incorporated parts of Xavier’s statement “higher the moisture the ... smellier” the compost pile will be. Seth also included evidence with his response; and he too identified the “higher moisture (level) is stinkier” though he did not include the evidence he had stated that the compost would decompose slowly. The boys’ interaction is in contrast to the girls’ because the girls did not question Bayley’s claim with evidence. The girls were able to follow Bayley’s claim and evidence and reason that it was the appropriate response to the question. Seth, similarly, provided evidence that the trial had a slow decomposition rate and produced stinky compost; two things that indicated the trial was unsuccessful, yet, his idea was not considered among the rest of the group.

Table 22

**I-1 Male group’s responses in Team journal**

<table>
<thead>
<tr>
<th>Journal Prompt</th>
<th>Student</th>
<th>Written Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>What was the result of trial 1? Was decomposition successful? Explain how you know:</td>
<td>Xavier</td>
<td>Yes, trial 1 was successful because we thought that (did not complete his response)</td>
</tr>
<tr>
<td></td>
<td>Cedric</td>
<td>Yes, because the higher the moisture is the more it will smell.</td>
</tr>
<tr>
<td></td>
<td>Seth</td>
<td>Yes, higher moisture is stinkier.</td>
</tr>
</tbody>
</table>

**I-2 implementation – Carbon and Nitrogen Ratio Virtual Experiment.** The I-2 Female group had four instances of argumentation during the Carbon to Nitrogen Ratio virtual experiment. Two instances of argumentation were simple claims without justification or evidence and the other two instances included a claim with evidential support. Just like the I-1 students three of the four instances of argumentation occurred as the girls were responding to the questions associated with each trial in the team journal. The other instance of argumentation
occurred prior to the girls participating with the *Carbon to Nitrogen Ratio* virtual experiment.

Charlotte wrapped up the group’s causal chain (see Figure 15) from the previous virtual experiment that had students explore the effects of particle size on the rate of decomposition.

2. Create a cause-and-effect chain to show how particle size affects the decomposers and decomposition rate in compost. Circle *one* option under each part of the chain (particle size, air circulation, and decomposition rate) to create a cause-and-effect chain that makes the most sense. There can be more than one correct causal chain. (The “→” means causes or leads to.)

**Particle Size**
- Small (~20mm or less)
- Medium (~50mm)
- Large (~80mm)

**Air Circulation**
- Aerobic
- Anaerobic

**Decomposition Rate**
- Fast
- Slow

Explain your choice using data you collected and / or what you have learned on VidyaMap.

---

*Figure 15. Causal Chain – Virtual Experiment*

**Charlotte:** I’ll circle. I can circle. I can do that. I can draw a circle. I already know this, this is easy, this is medium, aerobic, decompose for having that energy to grow, uh, approximate and fast. It’s easy. Right? Cause we got that one, when we put that in it was right, it worked. Right?

**Sasha:** Hmm?
Charlotte: Right?
Sasha: Well –
Charlotte: Because when we put that in, it worked and it was fine.

Charlotte expressed her claim about the causal chain and sought confirmation from her group mates. Sasha attempted to examine the work that Charlotte presented her but Charlotte did not allow Sasha time to process her statement about the causal chain. Charlotte sought a quick confirmation of her idea, similar to what had transpired between the girls in previous activities.

In the *Carbon to Nitrogen Ratio* virtual experiment, over half of the instances of argumentation that occurred between the girls were of an individual presenting a claim without justification/evidence, and seeking confirmation or approval of their idea. The I-2 implementation differed from the I-1 implementation in that it included the collaborative role of the Skeptic. However, the inclusion of the Skeptic role did not seem to have a strong influence on the girls asking for or providing evidence to support their claims.

Like the female group, the I-2 Male group engaged in a low number of instances of argumentation (4) during the *Carbon to Nitrogen Ratio* virtual experiment. Two of these instances were more complex with counter claims along with evidence/justification provided.

The boys engaged in a long instance of argumentation about the carbon to nitrogen ratio of 36:1. Both Roman and Finn achieved the ratio of 36:1 on their individual laptops, but used different combinations of the organic material (greens and browns) to achieve the ratio. Finn claimed that the outcome from both set-ups would be the same, but Roman disagreed because of the different materials the boys used to achieve the 36:1 ratio.

Jey: We need to find the highest. (highest point of the range for fast decomposition)
Finn: 36 don’t work [points to his laptop screen as he speaks]
Roman: Here we go [Turns laptop screen to face group and points to the screen]. This means brown 1, brown 2, and brown 3.
Finn: That won’t work.
Roman: Yes it will. I think
Finn: [shaking his head ‘no’] I just tried it.
Roman: Just write it down, we’ve got to write it anyways. Really Jey.
Jey: I’m trying.
Finn: Simulate it, watch.
Jey: I mean like, Roman
Roman: Get your eraser
Finn: I got 36 again [Roman leans over and looks at Finn’s screen]
Jey: So green mixture.
Roman: All you are using is brown 1, I’m using brown 1, 2, and 3 and the greens.
Finn: Ohh. Let me add some greens.
Roman: See!
Finn: That’s 34.
Roman: Yeah, that would be [does not complete sentence].
Finn: Watch
Roman: That’s not what I did. We used different ones. You used only two things, I – I used four things. It might end up as different. It might end up differently.
Jey: Yeah, you didn’t use all the things he used.
Finn: It is still the same number.
Jey: No.
Roman: It-it is but it’s still gonna be it might turn out differently.
Jey: [inaudible] decompose, I’m fairly sure.
Roman: You used only two things and this might end up differently to what that is.
Finn: Well, what ya do? A whole lot of greens.
[Over a minute passes as Roman sets up the virtual experiment]
Roman: [Roman hits the simulate button]
Finn: Oh. Wait, it’s okay but the decomposition rate is low though.
Finn: Told you. . . . I told you it was low.

This episode demonstrates a complex instance of argumentation that occurred between Finn, Roman and Jey. Finn made the initial claim that the ratio 36:1 did not work. However, Roman and Jey did not initially acknowledge Finn’s claim. Roman countered that he thought the 36:1 ratio would achieve a fast rate of decomposition but did not provide justification for his counter claim until Finn showed that he had achieved the same ratio on his laptop and it did not work. In response, Roman countered again that they used different organic material to create the 36:1 ratio which he used as his justification for why the outcomes would be different. Finn,
however, was not swayed by his peers; based on the result of his previously conducted experiment Finn knew that the decomposition rate would be slow. Finn stood firm with his counter claim and supporting evidence that despite having used different materials to generate the 36:1 ratio the rate of decomposition would still be slow. In the end, the data supported Finn’s claim.

Case Summary. The total number of questions posed was significantly higher during the Virtual Experiments than any other activity, yet Social Questions dominated the type of question posed, suggesting that the students were easily distracted. As noted above, the students in the I-2 groups each had their individual laptops out running the virtual simulations on their own despite the teacher instructing students to use one laptop. This influenced how the students interacted with each other. The students in the I-1 groups often made decisions together about what and how much material they should add to the simulation and took turns on who ran the simulation. The I-2 groups often repeated virtual trials multiple times due to their lack of communication among group members on who was doing what on each laptop. So even though the I-2 groups posed more Inquiry/Science Content type questions, these questions were focused on clarifying what occurred in each trial the individual students conducted and not directly for their growth of understanding decomposition in compost.

The number of instances of argumentation during the virtual experiments was lower than the Making Observations (Card Sort) activity; however, three of the groups engaged in at least one complex instance of argumentation such as providing evidence or justification for a claim. The design of the virtual experiments encouraged students to provide evidence for their thinking, specifically when students were talking about the results of the virtual trials. In the videos students pointed to the laptop and their team journals to provide evidence to support their
thinking. This is promising since students were not provided any information on how to engage in argumentation within the curriculum.

**Case 4 – Big Ideas about Ecosystems activity**

**Description of activity.** The *Big Ideas about Ecosystems* activity occurred near the end of the curricular unit. The activity preceded the students’ final compost bio-reactor observation where they recorded their final qualitative and quantitative observations about their compost. The *Big Ideas about Ecosystems* activity was the least hands-on activity of the four examined for this study. Students had spent the previous two class periods using the VidyaMap to explore the topic of ecosystems and even investigated their own ecosystem as a group. The examined task was a culminating activity that asked students to use data collected from the previous days’ activities to summarize their knowledge about ecosystems. Students were instructed to think about their group’s investigation of an ecosystem, focusing on abiotic and biotic factors, interactions between organisms (i.e., producers, consumers, and decomposers), and the cycling of matter in a compost pile. The goal of the task was to wrap up the larger discussion about ecosystems and to prepare students to think about compost as an ecosystem.

The *Big Ideas about Ecosystems* activity was conceptually the same in both implementations; however, the I-2 curriculum used a series of questions to support and guide student thinking. In the I-1 implementation the students were instructed to reflect on the previous tasks and think about what it meant for something to be an ecosystem. It was set up as a T-C-S cycle, which the teacher followed, providing students time in each phase of the cycle. Students also wrote their group’s ideas on a Padlet post (see Figure 16) in order for the teacher to structure the whole group Share segment. In the I-1 curriculum there was space provided in the students’ journals for them to take notes about their ideas about ecosystems (see Figure 17). Students were
instructed to discuss in their group what they had learned about what it meant for something to be an ecosystem.

Figure 16. Padlet Wall – Big Ideas about Ecosystems
Figure 17. Implementation 1 Team Journal

In Implementation two, students were given the same task however the team journal provided more structure that supported students during their small group discussions about ecosystems. Instead of a blank area to write down their ideas the I-2 curriculum had three questions that guided students. These questions focused on the interaction of abiotic and biotic factors of an ecosystem; the interactions between decomposers, producers, and consumers; and the cycling of matter in compost (Figure 18). The structural differences between the I-1 and I-2 curriculum did not alter how the teacher organized the classroom time in the I-2 implementation. The I-2 groups also followed the T-C-S cycle and utilized a Padlet wall to share students’ ideas.
**Big Ideas about Ecosystems**

Think back to your group's investigation of your own ecosystem, and what you have learned about the relationships between biotic and abiotic factors by monitoring your own compost. Let's discuss what we have learned about what it means for something to be an ecosystem!

First, discuss with your group. Then, be prepared to explain your ideas to the class and support them with evidence!

Scientists use their data and research to make statements about how they think the world works. When you make a statement or give an explanation, you must back it up with evidence to convince others!

---

**In your group's investigation of your ecosystem what did you learn about the interaction of abiotic and biotic factors?**

---

**What did you learn about the interactions between decomposers, producers, and consumers?**

---

**Do your responses to the above questions match the cycling of matter occurring within your compost?**

---

**Figure 18. Implementation 2 Team Journal**

**Questions and Big Ideas about Ecosystems activity.** Students asked the least number of questions during the *Big Ideas about Ecosystems* activity, which is not surprising since it was the least interactive activity of the four selected for this study. The task of responding to either one or three questions was very straight forward therefore the four groups posed only 13 *Task Oriented* questions. Most of these questions were about whether or not the group needed to
create a Padlet post. Students Inquiry/Science Content focused questions were also low with only 23 questions posed during the activity, accounting for only 15% of the questions students asked. The Other and Materials focused questions were also low due to the nature of the activity. However, Social questions accounted for 50% of the questions asked, suggesting that the students spent a large amount of time off task. The simplicity of the activity and the repetitive nature of the task could have led to the large number of Social questions and so few Inquiry/Science Content questions. The Big Ideas about Ecosystems activity was also near the end of the curriculum; students potentially had a stronger understanding of the science content being covered, and therefore no longer had a need to pose as many Inquiry/Science Content questions.

Most of the Inquiry/Science Content questions occurred early in the Collaborate segment when students Prompted someone to share their idea about the question(s) they were required to respond to in their team journals. By this time in the implementation students were good at prompting each other to share their understanding and incorporating their pieces of knowledge together to formulate a group response. The Prompting someone to share their idea questions was the most common way students started the Collaborate segment. The other type of question that was prominent in this activity was the Seeking clarification/explanation of peer’s ideas. These were used when someone did not understand a group member’s idea. These types of questions were common across all activities that required students to discuss and write down the group’s response or create a single group Padlet post. Table 23 displays a few of these two types of questions that students posed during the Big Ideas about Ecosystems activity.
Table 23

*Big Ideas about Ecosystems – Inquiry/Science Content questions*

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prompting someone to share their idea</strong></td>
<td>What do you think an ecosystem has to have? – Alexa</td>
</tr>
<tr>
<td></td>
<td>What do you have? – Charlotte</td>
</tr>
<tr>
<td></td>
<td>What you got? – Xavier</td>
</tr>
<tr>
<td></td>
<td>Do you have any ideas? – Finn</td>
</tr>
<tr>
<td><strong>Seeking clarification/explanation of peer’s idea</strong></td>
<td>What does that mean? – Roman</td>
</tr>
<tr>
<td></td>
<td>Abiotic and biotic things? – Nia</td>
</tr>
<tr>
<td></td>
<td>Wait a minute! They don’t have what? – Bayley</td>
</tr>
</tbody>
</table>

The low number of *Inquiry/Science Content* questions (23 out of 157) is not surprising since the *Big Ideas about Ecosystem* activity was meant for students to reflect upon and summarize their newly acquired knowledge. Students were no longer exploring the topic of ecosystems; they were synthesizing their understanding of ecosystems. The goal of the activity was for students to respond to the questions provided in their team journal. Overall there was lower engagement with the material and less discussion about the science content than the previous activities. This was noted by the students’ ability to achieve quick consensus during the activity, and by students finishing the task quickly or procrastinating until they only had a few minutes left to create their Padlet post, thus requiring the group to rush in order to generate their response.
Argumentation and Big Ideas about Ecosystems activity. Despite the simplicity of the activity the groups engaged in a few instances of argumentation. Overall, the Big Ideas about Ecosystems activity had the fewest instances of argumentation (17) and they were the least complex arguments of the four activities. Of the 17 instances, 11 were simple claims without justification/evidence and no follow up discussion associated with the claim. Three of the 17 instances consisted of a claim without justification/evidence but did have a simple disagreement (i.e., “No” or “I don’t think so”). In these instances the simple disagreement negated the initial claim but did not provide a counter claim. The I-2 Male group was the only group to engage in a more robust discussion that involved a claim with supporting evidence followed by a counter claim. This, however, was the exception and not the rule during the Big Ideas about Ecosystems activity.

The I-1 Female group initially expressed their individual claims they had written about what it meant for something to be an ecosystem. Multiple extended pauses occurred during the girls’ presentation of ideas partly because Alexa was still writing when the Collaborate segment began. Each girl had a slightly different claim that included different components of an ecosystem. In the exchange below Nia, Bayley, and Alexa each shared what they had written during the Think segment.

Nia: I got. I think an ecosystem must have many interacting components. Umm abiotic and biotic factors which is plants and animals.
Alexa: I’m almost done. (goes back to writing in her journal)

(40 second pause in conversation)

Bayley: Okay. I said I think an ecosystem has abiotic and biotic things and producers for photosynthesis plus oxygen and air.
Nia: Abiotic and biotic things?
Bayley: Yeah.
Alexa: Okay. I think an ecosystem has to have habitats for animals to live in and food source of some type and at least a little bit of water depending on what the ecosystem is. The ecosystem also needs to have abiotic and biotic factors and some interacting with each other.

Nia: Well I got mines I got this when I was looking at umm that thing Vidyamap.

All three girls expressed their thinking to the group, though Nia presented the only instance of questioning another student’s idea when Bayley stated abiotic and biotic things instead of factors. Nia’s question did not elicit a conversation about abiotic and biotic factors, Bayley simple responded “yeah” and then the conversation was dropped. The girls did not engage with the science content beyond stating their claim to the group; nor did they provide justification for their thinking. Nia noted at the end of the segment that she got her information from the Vidyamap, which was the only occasion of one of the girls attempting to provide some form of evidence to support their thinking. A few moments later the girls worked through what they should write down in the journal as their group response for the Collaborate segment. The following instance of argumentation showed how Alexa incorporated ideas from each of the girls’ individual writing into the group consensus. The conversation began when Nia expressed to the group that they only had a few minutes to write down their group’s response.

Alexa: Okay. We will take yours. We’ll take yours.
Nia: Ecosystems ecosystems must have ugh umm put ecosystem must consist of many interacting components that are both living and non-living. The living parts are called biotic factors and [brief pause; looks at Alexa who is coloring instead of writing down what Nia is saying] Man! Write it down! We only have 1-minute left.
Alexa: Where do I write this down? Here? Okay read yours.
Nia: I think We think we think. We think an ecosystem must consist of many interacting components that are both living and non-living.
The living parts are called biotic factors and the non-living parts are called abiotic factors.

Alexa: Okay. I got.
Bayley: All ecosystems have to have some type of producer to carry out photosynthesis.
Alexa: Okay. So I am just going to add the ecosystem needs to have producers.
Nia: That is umm non-living the abiotic.
Alexa: Well that’s what she told me to say. Producers umm composers, no what are the ones that eat?
Nia: Consumers and decomposers.
Alexa: Consumers, decomposers, and scavengers.

This was the girls’ most complex instance of argumentation during the Big Ideas about Ecosystems activity. It demonstrates how Alexa constructed the group’s claim from the individual ideas generated during the Think segment. Bayley’s introduction of producers into the conversation prompted Nia to clarify, incorrectly, to Alexa “that is [producers] umm non-living the abiotic.” Nia’s clarification can be interpreted as a disagreement about including the term producer in their group’s response. Nia introduced both instances of disagreement or question, coincidentally about things that Bayley proposed. Though the instances of argumentation were not robust, they do demonstrate the students’ ability to engage in knowledge integration. The episode above also displayed how students would question one another in order to achieve clarity of each other’s ideas. Alexa was able to incorporate various aspects of each girls’ understanding what belongs in an ecosystem into the group’s response, which they shared with the class via Padlet. Alexa frequently volunteered to be the group’s Reporter; therefore, she was often the group member who was integrating everyone’s ideas and was ultimately in charge of how the group responded to questions.

The I-1 Male group had three instances of simple claims presented to the group and one instance of a claim followed by a statement of disagreement. The group was constantly being distracted by the table behind them which caused them to veer off topic easily. In fact, an
example of this occurred as soon as the class was released to begin the Collaborate segment.

Xavier began the segment by providing the group with what he had written in his journal, “A place that has different types of animals and plants there.” No discussion occurred after Xavier presented his idea to the group, because Xavier and Cedric both turned in their chairs to look at the table behind them immediately after Xavier finished reading his statement. Over three minutes later the boys turned around and Xavier prompted the following brief dialogue:

Xavier: What you got?
Cedric: I got an ecosystem is a place where you see animals, plants, and humans and different (inaudible).
Xavier: Let me see what you got. [leans over to read from Cedric’s journal] Were you so
Cedric: No, no no this one right here. [points to writing in his journal]
Xavier: An ecosystem is a place where you see animals, plants, and humans. You don’t see no (stops abruptly)
Cedric: An ecosystem. An ecosystem is where you see animals, plants, or humans.

Xavier does not complete his sentence that started “You don’t see no,” suggesting that Xavier disagreed with part of Cedric’s claim. I note that it only suggests that Xavier disagreed because no further dialogue happened between the boys. When student journals were reviewed both Cedric and Xavier had Cedric’s definition written down which included animals, plants and humans. The activity did not generate a lot of on-topic discourse among this group. They accepted each other’s responses with little push back and discussion. In fact it is over ten minutes later that the final instance of argumentation occurred for this group while they typed their Padlet note. Cedric turned to Xavier and stated, “Xavier, Xavier. You know what, an ecosystem has to have abiotic factors and biotic factors interacting with one another.” Xavier does not look up from the laptop nor does he respond verbally to Cedric’s proclamation; however, Xavier does add a line to their Padlet note that states that ecosystems have biotic and abiotic factors.
Both I-1 groups were distracted and at times disinterested in the task. Both groups did complete the task in the journal and created a Padlet post, but the conversation between group members was minimal. The I-2 groups were slightly more engaged during the Big ideas about Ecosystems activity, this can partly be explained by the design changes that occurred between implementations. The I-2 groups had more guidance on how to summarize their understanding provided by three questions as opposed to the I-1 group’s instruction to discuss what it means to be an ecosystem.

The I-2 Female group engaged in five instances of argumentation during the Big ideas about Ecosystems activity. Four of the five instances were simple claims without justification/evidence along that included no other conversation about the claims. The other instance of argumentation was a single claim without justification/evidence but included a simple disagreement. Charlotte and Tamina disagreed with Sasha’s response to a question in the team journal, but the girls did not formally present a counter claim. The four unsupported claims occurred at the beginning of the Collaborate segment when Charlotte shared her response to question one and then later as she was typing the group’s Padlet note.

The girls struggled to work collaboratively during this activity. Charlotte was the only one who consistently shared her ideas with the group, which is in contrast to Sasha who shared once and Tamina who shared nothing. In fact, Tamina prevented Sasha and Charlotte from reading her ideas off of her notebook paper by snatching it away from her group mates when they attempted to read her work. The following exchange is the only time Sasha shared with the group.

Charlotte: I put. Okay. The biotic factors help make things that are used for abiotic factors. Okay. (Turns to Sasha.) What do you have? (brief pause) TTTdddaaa. Sasha. (brief pause) What do you have? Huh?

Sasha: Huh?
Charlotte: What do you have for the first one?
Sasha: Wait. What do you mean?
Charlotte: What did you put?
Sasha: It’s abiotic is non-living.
Tamina: You weren’t supposed to define the term.
Charlotte: [very frustrated] You weren’t supposed to define it! You were just supposed to do it.

Charlotte became frustrated with Sasha and their interactions for the rest of the Collaborate segment reflected the frustration. The group did not talk nor work as a group like they had in previous activities thus negatively influencing their interactions as a whole and the complexity of argumentation that resulted. The tension between Charlotte and her peers lasted the entire collaborate segment, while Charlotte was working on the group’s Padlet post she refused to let Sasha see what she was typing. Charlotte held her laptop in her lap away from the group and read what she had typed to the group instead of placing the laptop on the table where everyone could see the screen. The Padlet post reflected Charlotte’s claim she had read aloud to the group earlier in the class period. The lack of discussion and overall interest in completing the task caused friction between the girls, specifically Charlotte and Sasha, which impacted how the girls communicated and collaborated. The interactions were not characteristic of how the girls worked together during the other activities discussed in this study.

The I-2 Male group engaged in four instances of argumentation; these were the most complex instances that occurred during the Big Ideas about Ecosystems activity. Finn was responsible for starting three of the four instances of argumentation because he consistently asked for either an explanation or evidence from his peers. The first instance of argumentation was the most complex because of the counter claim Finn posed to Roman about air and sunlight. For example, Finn questioned what Roman had written on his paper and continued to push Roman for an explanation.
Finn: The air and plants use sunlight.
[read verbatim from Roman’s notebook paper]
Why does it say the air uses sunlight?
Roman: Hmm?
Finn: Does air use sunlight? It said, read it. The air and plants use sunlight. The umm air don’t use sunlight.
Roman: By drinking water or breathing in the air.
[points to paper as he reads]
Finn: I don’t have [inaudible].
Roman: [reading from notebook paper]
Abiotic factors, drinking water or plants using sunlight.

Finn did not understand the statement Roman had written on his paper, Finn continued to question Roman until he received an explanation. Finn was assertive and asked for an explanation when he didn’t understand which was unique and not something other students did on a consistent basis. This episode also demonstrates how a student’s inquiry can directly influence argumentation among group members. Finn used two questions to initiate a conversation with Roman in order to clarify the science content. Another interaction between Finn, Jey, and Roman that was not as complex as the previous instance but also demonstrates Finn’s desire for an explanation when he does not understand a scientific concept. Jey and Finn had previously discussed the third question posed in the Big Ideas about Ecosystems activity, but they struggled to understand what the question was asking them. The question states: Do your responses to the above questions match the cycling of matter occurring within your compost?

Roman: What’s number 3?
Finn: We [him and Jey] can’t figure it out. Here you read it.
[Hands Roman the team journal]
It don’t even make sense when you read it. Do your response.
Roman: It kind of does.
Jey: It makes sense.
Finn: I don’t get it.
Roman: [Talks while typing] It-kind-of-does.
Finn: Explain it!
Roman: I don’t know how to explain it!
Finn: That’s why I asked you to explain it because we are so lost.
Roman: It doesn’t say explain. It just asked us.
Jey: Wait, ugh, Mr. J said [trails off and doesn’t complete sentence].
Finn: It says explain.
Roman: Ughh I don’t know. [pause] Oh wait. It kind of does [begins typing and talking at the same time]. Because-when-we-started-the-
experiment-the-greens
Finn: I don’t know.
Roman: the-greens-were-still-alive-so-they-were-still [pause]. They were still [long pause].
Finn: I don’t understand.
Roman: Oh yeah! So-they-were-still-taking-sunlight-to
Finn: They were taking the heat from the light.
Roman: to-use.

Here Finn pushed Roman to explain question number three to him. Finn’s insistence for an explanation was not a counter claim, but rather asked Roman to provide evidence/justification for his thinking. Roman’s initial response, “It kind of does,” was not a satisfactory answer according to Finn. Finn urged Roman to explain the question and his response to him until Roman admitted that he did not know how to explain the concept. Finn’s desire to know more about the concept encouraged Roman to think deeper about his response. Eventually, Roman provided an explanation making the group’s claim stronger and more coherent.

Case Summary. The Big Ideas about Ecosystems activity was not designed to engage students in complex instances of argumentation or to inspire inquiry. The goal of the activity was for students to reflect on and summarize their understanding of ecosystems. Even though questioning and argumentation were not goals of the activity students were able to engage in both of these actions at moderate levels. The two types of Inquiry/Science Content questions posed the most were Prompting someone to share their idea and Seeking clarification/explanation of a peer’s idea. These two types of questions were used to begin conversations and to clarify students’ ideas about ecosystems. Instances of argumentation were also low as most students readily agreed about the different aspects of an ecosystem. Even
though the Big Ideas about Ecosystems activity elicited the lowest number of questions and instances of argumentation of the four activities there were still moments in which students questioned and argued with their peers. For instance, Finn, from the I-2 male group, was assertive and displayed a questioning nature that encouraged his group mates to provide more coherent and complete claims.

**Cross-Case Analysis**

The four activities selected as a part of this study represented four unique ways students engaged with the content material. Each activity provided students opportunity to engage with science content in a collaborative small group setting. The four activities examined for this study elicited 1,120 questions and 131 instances of argumentation from students. Several factors impacted the phenomenon of student-generated questions and their instances of argumentation during the curricular implementations. The following cross-case analysis provides insight into how the individual activities influenced student questioning both in the major category themes (i.e., Materials-Focused, Task Oriented, Other, Social, & Inquiry/Science Content) and specifically the sub-categories of the Inquiry/Science Content questions (See Appendix I for complete list of question categories and sub-categories).

Analysis revealed connections between the Inquiry/Science Content questions and the instances of argumentation that occurred in the four activities. The connection suggests that the type of Inquiry/Science Content question elicited from students influenced their arguments and their learning. Ultimately, the specific types of Inquiry/Science Content questions asked shaped student discourse and argumentation. In turn, the analysis revealed the types of Inquiry/Science Content questions asked were influenced by the placement of the activity in the curriculum and the structure of the activity (see Figure 19).
Placement of activities in curricular unit. The four activities sampled and examined for this dissertation spanned the length of the curricular unit. The findings suggest placement of the activities had a slight influence on the Inquiry/Science content questions students generated. The earlier in the curricular unit the activity was, the higher the percentage of Inquiry/Science Content questions students posed during the activity (see Table 24). For example, the Making Observations (Card Sort) activity was the first activity examined for this study and it was the third activity in the Compost curriculum. It had the largest percentage of Inquiry/Science Content questions, 43%, asked during the activity. As the implementations progressed the percentage of Inquiry/Science Content questions generated by students during an activity steadily decreased. The What Factors? activity was the eighth activity in the curricular unit and 32% of the questions were identified as Inquiry/Science Content questions. The Virtual Experiments
occurred closer to the middle of the curricular unit and 19% of the questions students posed during the virtual experiments were *Inquiry/Science Content* questions. Finally, *Big Ideas about Ecosystems*, which was one of the last activities in the unit, had only 15% of the questions posed identified as *Inquiry/Science Content* questions.

One reason why this might have occurred was that the Compost curricular unit was new and different from prior units and activities the students experienced in their science classroom. Hence, the earlier activities were novel, thus, elicited more curiosity from students than the preceding activities. Students were also gathering and working with new science content in the beginning of the Compost unit, as time progressed they were working on refining their understanding as opposed to gathering new information. Finally, the Compost curriculum took eight weeks to implement and the extended time on a single, comprehensive unit could have overwhelmed students in the later weeks of the implementation. Fatigue could have set in by the time students participated in the *Big Ideas about Ecosystems* activity.

Table 24

*Types and frequencies of questions asked by students during activities*

<table>
<thead>
<tr>
<th>Types of Questions</th>
<th>Social</th>
<th>Materials</th>
<th>Task Oriented</th>
<th>Other</th>
<th>Inquiry/Science Content</th>
<th>Total</th>
<th>% Inquiry/Science Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Card Sort</em></td>
<td>31</td>
<td>29</td>
<td>34</td>
<td>29</td>
<td>92</td>
<td>216</td>
<td>43</td>
</tr>
<tr>
<td><em>What Factors?</em></td>
<td>65</td>
<td>33</td>
<td>36</td>
<td>32</td>
<td>77</td>
<td>243</td>
<td>32</td>
</tr>
<tr>
<td><em>Virtual Experiment</em></td>
<td>168</td>
<td>94</td>
<td>90</td>
<td>57</td>
<td>96</td>
<td>505</td>
<td>19</td>
</tr>
<tr>
<td><em>Big ideas about ecosystems</em></td>
<td>78</td>
<td>24</td>
<td>13</td>
<td>19</td>
<td>23</td>
<td>157</td>
<td>15</td>
</tr>
</tbody>
</table>
Social questions had the inverse pattern of the Inquiry/Science Content questions, as the implementations progressed the percentage of Social questions increased. The Making Observations (Card Sort) activity had the lowest percentage of Social questions (14%) of the four activities. The percentage increased from activity to activity; What Factors? 27%, Virtual Experiments 33%, Big Ideas about Ecosystems 50%. The final activity, Big Ideas about Ecosystems, examined in this study provided further evidence that the placement of the activity influenced student-generated questions. Big Ideas about Ecosystems had the fewest questions posed overall with 157 questions asked by all four groups, which was nearly 60 less than the next activity. There could be several reasons for this finding; one could be that it was the end of the 8-week unit, therefore, students could have had a stronger grasp on the science content and did not need to pose as many questions. A second explanation for the drop in questions asked is that students had moved beyond exploring the topics presented in the curriculum to constructing explanations to demonstrate their understanding. Therefore, suggesting that the structure of the activity had a greater influence on the questions students posed and their instances of argumentation. The next section explores this idea in further detail.

**Structure of activities.** The design, goals, and the structure of the activity impacted the number and type of student-generated questions. The activities that had higher percentages of Inquiry/Science Content questions were inquiry-based, hands-on, and had exploratory elements. These activities captured students’ attention and kept them focused while they engaged with science content. The first three activities studied in this dissertation had these featured elements and as a result had the most Inquiry/Science Content questions posed during the activities.

The first activity, Making Observations (Card Sort), required students to categorize statements as either qualitative observations, quantitative observations, or inferences. The hands-
on aspect of moving the cards around the table encouraged students to question each other about the categorization of each of the cards. In addition to manipulating the cards, some of the statements and pictures provided on the cards encouraged students to disagree with one another. For example, Xavier and Seth each provided their own claim with justification/evidence about how to classify the card labeled ‘Temperature’. Seth focused on the words provided on the card while Xavier used the picture of the thermometer to support his thinking. The I-2 Female group of Tamina, Charlotte, and Sasha engaged in argumentation about two cards that included both quantitative and qualitative observations. The inclusion of both types of observations on a single card was designed to elicit conversation from students so they could discuss the different aspects of making observations and the differences between qualitative and quantitative observations.

The What Factors? activity, the second activity analyzed for this study, did not have a hands-on element to it but students wrote their own research questions. Thus providing students an opportunity to conduct their own inquiry and explore their own questions regarding the factors of decomposition. The activity began with students brainstorming with their group mates about the different factors of decomposition, this provided students an opportunity to activate their prior knowledge on the topic. Additionally, students used the group’s knowledge to write their own research questions, which they then explored the next day in class. This gave students autonomy over their own learning and allowed the students to decide what they would be researching the next day.

The third activity explored in this study, the Moisture and Carbon to Nitrogen Ratio virtual experiments, provided students the opportunity to engage in their own inquiry in a unique virtual simulation. The structure of the virtual experiments allowed students to explore the different factors that influence the rate of decomposition in a compost pile through the
manipulation of different variables. As noted above the percentage of Inquiry/Science Content questions was low during this activity. However, the low percentage is not indicative of the actual number (96) of Inquiry/Science Content questions students posed during the virtual experiments which was the highest of the four activities. The virtual experiments were not typical of students’ science instruction and were a new experience for many of the students in this context. This created a learning curve that the students did not have in the other activities. Students first had to learn how to navigate to the virtual experiments website, how to login, and then determine how the experiment functioned before they could engage with the science content material. These necessary tasks caused an increase in the number of Task Oriented and Materials Focused questions posed by the students. The increase in these two types of questions caused the percentage of Inquiry/Science Content questions to be lower than the first two activities.

A main goal of the virtual experiments was for students to find the ideal carbon to nitrogen ratio and moisture range suitable for decomposition in a compost pile. Students became invested in achieving the lowest and highest carbon and nitrogen ratio and percent moisture. For example, Jey, Finn, and Roman worked for several minutes and engaged in an instance of argumentation over whether or not the ratio of 36:1 was a part of the ideal decomposition range. This instance of argumentation included multiple claims, counter claims, evidence to support claims, and justification for individual thinking. The argument concluded when the data from the virtual experiment supported Finn’s initial claim that the ratio 36:1 was not a part of the ideal range for decomposition. The goal of finding the ideal range along with the design of the virtual experiment supported and encouraged the boys to discuss science content and as well as engage in a complex instance of argumentation.
The final activity *Big Ideas about Ecosystems*, was structured so that students would reflect on what they had learned, they were beyond the exploratory phase of the curricular unit thus the students asked few *Inquiry/Science Content* questions. During this activity students only asked 23 *Inquiry/Science Content* questions, in fact the *Big Ideas about Ecosystems* had the fewest questions posed overall of the four activities. In general students were less curious during this activity and focused on completing the task so they could then engage with other things. Additionally, students engaged in very few instances of argumentation during this activity. For one the design of the activity was for students to respond to pre-written questions in their team journal. The questions only encouraged students to respond with simple definitions of science content that they had been discussing in prior activities. The questions did not urge students to think beyond simple vocabulary definitions.

**Type of Inquiry/Science Content question.** The design, goals, and structure of the activities influenced how many *Inquiry/Science Content* questions students asked. These factors also influenced the specific type of *Inquiry/Science Content* questions students posed, which in turn influenced the instances of argumentation and the overall discourse that occurred during the activities.

Analysis revealed that the different types of *Inquiry/Science Content* questions were more prevalent in each of the activities. As noted in Table 25, the *What Factors?* activity had significantly more students *Proposing potential research* questions than the other three activities, 28 of the 31 questions asked. This is not surprising since one of the goals of the *What Factors?* activity was for students to generate their own research questions. This can be contrasted with the virtual experiments which had more students *Asking for an explanation for an observed phenomena*. The virtual experiments were the only activities examined in this study that
provided students an opportunity to observe a scientific phenomenon, therefore this type of Inquiry/Science Content question was more prevalent than in other activities. Asking for an explanation of an observed phenomena type questions typically occurred after students completed a trial of the virtual experiment and were examining the results. These are just two examples of how the design of an activity influenced the type of Science/Inquiry Content questions students posed.

Table 25

Type of Inquiry/Science Content questions per activity

<table>
<thead>
<tr>
<th>Inquiry/Science Content Question</th>
<th>Card Sort</th>
<th>What Factors?</th>
<th>Virtual Experiments</th>
<th>Big Ideas about Ecosystems</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposing potential research</td>
<td>3</td>
<td>28</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Prompting group member to share their idea</td>
<td>3</td>
<td>11</td>
<td>2</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>Asking for an explanation for an observed phenomena</td>
<td>1</td>
<td>4</td>
<td>13</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Prompting group to extend thinking</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Seeking Clarification/explanation of another student’s idea</td>
<td>27</td>
<td>21</td>
<td>41</td>
<td>10</td>
<td>99</td>
</tr>
<tr>
<td>Asking for evidence</td>
<td>18</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Seeking affirmation/confirmation of a concept</td>
<td>20</td>
<td>4</td>
<td>7</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>Seeking input on a concept</td>
<td>21</td>
<td>8</td>
<td>27</td>
<td>5</td>
<td>61</td>
</tr>
</tbody>
</table>
The Making Observations (Card Sort) activity had significantly more Asking for evidence and Seeking affirmation/confirmation of a concept type questions than the other activities. This activity was designed to have students physically manipulate a set of cards as a way to engage them with scientific content. Students had more instances of argumentation during the Making Observations (Card Sort) activity therefore it is not surprising that the students asked for evidence more often during this activity than the others. The I-2 groups Asked for Evidence more frequently than the I-1 groups. The I-2 groups were responsible for asking 16 of the 18 Asking for Evidence questions posed during the Making Observations (Card Sort) activity. Students in the I-2 implementation had the external script of the Skeptic, a collaborative role, whose job was to ask for evidence and explanations during collaboration. This external script provided the I-2 students with extra support on Asking for Evidence; however, as noted earlier, students rarely Asked for Evidence in the other activities examined in this study. One reason this may have occurred is that as the unit progressed students were only reminded to use the collaborative roles, whereas during the Making Observations (Card Sort) activity the class discussed how to enact the roles in their small groups.

The design of the Making Observations (Card Sort) activity also lent itself to create a confirmatory discourse pattern of Seeking Affirmation/Confirmation of a concept. There were 33 questions of this type posed during the four activities and 20 occurred in the Making Observations (Card Sort) activity. For example, Bayley from the I-1 Female group struggled to distinguish the difference between quantitative and qualitative observations. She used a confirmatory question to gain affirmation of her understanding from her group mates when she asked, “Okay so this is words, numbers? Right? Words, numbers?” Other students also used similar questioning patterns during the Making Observations (Card Sort) activity when sharing
how they categorized the cards. The structure of the activity of physically manipulating the cards helped students to share their ideas with their group mates. Students used confirming questions as a way to provide their thinking to the group but also seek help in understanding the science concepts of qualitative observation, quantitative observation, and inference.

The above-mentioned types of Inquiry/Science Content questions were the questions that were unique to the specified activity; however, there were also a few types of questions that had high instances in multiple activities. One of those questions that had instances across multiple activities was the Seeking clarification/explanation of another student’s idea (99), in which all four activities had high instances. Only the What Factors? activity had a different type of question posed more frequently which was Posing potential research which was part of the outlined goals for the activity. It was encouraging to see that students sought an explanation and asked questions if they did not understand what their peer was talking about. For example, Finn in the I-2 Male group asked, “So the moisture is going to break it down?” This was in response to a claim Jey made about moisture and decomposition. This action was indicative of being a good scientist and relates to students being critical consumers of scientific information. As noted by Ford (2012), being critical consumers of information is not only important for science it is an important skill for students to have as they navigate our ever evolving world.

Another type of question that was heavily posed in multiple activities was Seeking input on a concept, both the Making Observations (Card Sort) and virtual experiments had high instances of this type of question. Charlotte, from the I-2 Female group asked, “What is Brown 1, Brown 2, Brown 3?” Similarly, Finn from the I-2 Male group asked, “What do we need? Do we want to add more Brown 2?” The browns refer to the type of organic material (carbon) that students could put into the virtual compost pile and influenced the carbon to nitrogen ratio. The
addition of the different browns influenced the rate of decomposition because of the varying carbon to nitrogen ratios the different organic material provided. Though *Seeking input on a concept* was not the highest posed type of question for either activity, they were influential in helping students navigate the virtual experiments and their understanding of factors that affect decomposition.

All activities in the Compost curricular unit, not just those examined for this study, had small group collaborative components to them. In each activity students were expected to work with their group mates to explore the science concepts presented in each lesson. As noted in the Chapter Three, each activity followed the Think-Collaborate-Share cycle, an external structure designed to support student collaboration, discussion, and learning. Each part of the T-C-S cycle was designed to support students in a different way. The Think time allowed for students to gather their individual thoughts about a topic, the Collaborate segment allowed each small group to share their individual understanding with each other and work through new information, and finally the Share segment helped structure whole class discussion. It is promising that the design of the Think-Collaborate-Share cycle potentially encourage students to discuss science concepts; specifically *Seek clarification/explanation of another student’s idea* and *Seek input on a concept*.

On another note, it was interesting to find that none of the activities overtly Prompted the groups to extend their thinking about the science content. These specific types of questions are similar to what Scardamelia and Bereiter (1992) called Wonderment questions. When students pose these types of questions their curiosity in science is ignited. Students go beyond what is expected and engage in the science for the sake of learning and not just for the goal of doing school (Scardamelia & Bereiter, 1992). For instance, the aim of the *What Factors?* activity was for students to generate their own research questions and eventually conduct the research. All
students contributed at least one research question, with most students staying within the realm of the science content that was covered in the curriculum. However, one student did Prompt the group to extend their thinking during the What Factors? activity. For example, Alexa asked, “Well, what if it is like fungi or something that doesn’t need sunlight?” Here Alexa challenged her group mates to broaden their thinking about what organisms needed to survive, due to some types of organisms not requiring sunlight. Alexa’s question extended the group’s thinking beyond what the Compost curricular unit necessitated.

As displayed in Figure 18, the placement of the activities in the curricular unit and the structure of the activity influenced the specific type and frequency of Inquiry/Science Content questions students posed. The earlier in the 8-week curricular unit and the more hands-on, inquiry, or exploratory elements the activities had the more Inquiry/Science Content-focused questions students asked. The structure of the activity specifically influenced the type of Inquiry/Science Content questions students asked. The Making Observations (Card Sort), What Factors?, and the Moisture and Carbon to Nitrogen Ratio virtual experiments each elicited a different amount of the various types of Inquiry/Science Content questions. These activities had students investigating the science content on their own, making their own choices, as well as exploring and researching the content on their own giving the students autonomy of their learning. The next section will describe the connection between the Inquiry/Science Content questions and the instances of argumentation that emerged.

Asking questions & argumentation. When looking at questions posed and the instances of argumentation that occurred in an activity an interesting trend emerged. The higher the percentage of Inquiry/Science Content questions the more instances of argumentation occurred during the activity (see Table 26). This trend does not take into account the complexity of the
arguments, just the occurrence of an aspect of an argument such as a student providing at least a simple claim. Though the trend does suggest that if students were curious and posed *Inquiry/Science Content* focused questions they are likely to engage in some aspect of argumentation.

Table 26

*Relationship between Inquiry/Science Content questions and instances of argumentation*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percent of Inquiry/Science Content questions</th>
<th>Number of Instances of argumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Card Sort</td>
<td>43</td>
<td>72</td>
</tr>
<tr>
<td>What Factors?</td>
<td>32</td>
<td>23</td>
</tr>
<tr>
<td>Virtual Experiment</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Big Ideas about ecosystems</td>
<td>15</td>
<td>17</td>
</tr>
</tbody>
</table>

The findings suggest that the structure of the activity not only influenced the type of questions students posed, it also impacted the number of instances of argumentation. The activities that had students exploring scientific concepts resulted in students posing more *Inquiry/Science Content*-focused questions and engaging in more instances of argumentation. For example, *Making Observations (Card Sort)* activity, had 72 instances of argumentation occur among the four groups examined in this study. All instances of argumentation had to include at least a claim in order to be counted as a part of argumentation. Therefore, the higher instances of argumentation demonstrated that the activity prompted students to produce scientific claims. However, it doesn’t tell us about the complexity at which the students argued.
The complexity of the instance of argumentation is important because it communicates the depth at which students engaged with the material. When students are able to provide evidence for their claim or provide a counter claim to an idea it indicates that a student was able to engage with the science content beyond a surface level. Complexity of an argument in this dissertation refers to a student supporting their idea and the push back or disagreement other students provide when a claim is presented (See Table 14. for complete description). Previous studies (e.g., Chin & Osborne, 2010b) have found that an activity must be structured in such a way that it provides students the opportunity to be curious and to disagree in order for students to engage in more complex instances of argumentation. My findings support this idea because students were able to engage in multiple instances of argumentation throughout the curricular unit, especially during the Making Observation (Card Sort) activity. This activity in particular was structured purposefully for students to organize their own thoughts, and then share their ideas with their group mates in order to generate discussion among the small group members. The design of the activity and specifically the ambiguous language (i.e., qualitative and quantitative observations presented on the same card) provided students the opportunity to disagree with one another as Charlotte and Sasha did over the placement of “The white couch has 3 cushions on it” card.

As demonstrated in Table 26. the Making Observations (Card Sort) activity provided students ample opportunity to engage in argumentation. However, the vast majority of these instances were not very complex (see Table 27). Many of the instances consisted of a student presenting their claim to the group with little to no discussion following. Yet, as Table 27 displays, it was the only activity that had an instance of argumentation that had a claim presented with evidence along with a counter claim that also included supporting evidence. Therefore, the
design and structure of the activity provided potential opportunities for students to engage in more complex instances of argumentation. This can be contrasted with the Big Ideas about Ecosystems activity that had the least number of instances of argumentation overall and few arguments that were identified as complex. The design of the Big Ideas about Ecosystems activity was not intended to help students explore science concepts, but was designed for reflection and summarization of student ideas generated over a series of activities. For example, one of the questions stated, “In your group’s investigation of your ecosystem what did you learn about the interaction of abiotic and biotic factors?” The question prompted different discourse among the groups of students than the other activities examined in this study.
Data analysis revealed that the majority of students’ instances of argumentation in all of the activities, 54%, included only the statement of a claim without any other group discussion. As noted in the Making Observations (Card Sort) activity case study, several students had a firm grasp of quantitative and qualitative observations; which allowed them to categorize the cards very quickly and achieve rapid consensus, this in turn accounted for the high percentage of low
complexity of argumentation (See Table 26). The virtual experiments, on the other hand, had the highest percentage, 47%, of claims supported with evidence compared to the other activities. The structure of the virtual experiments made it easy for students to support their claims with evidence because the students collected their own data from the virtual experiments. Several students were observed both pointing to the laptop screen or their journal page and reading the data output in order to support their claim with evidence.

Data or evidence, like that presented in the virtual experiments, was not as easily accessible in the other activities. For example, the Big Ideas about Ecosystems activity had only two claims supported by evidence despite the directions prompting students to do so. The expectation for students to support their ideas with evidence but the lack of explanation of how evidence was defined or a description of what the evidence looked like made the task challenging. The evidence in Big Ideas about Ecosystems activity was more difficult for students to identify compared to the virtual experiments because it was not data they had collected during an experiment but data collected through research in the VidyaMap. Students easily presented their ideas about ecosystems but struggled to provide evidence to support those ideas. Providing appropriate supporting evidence has been found to be difficult for students (Berland & McNeill, 2010; Kuhn 2010; McNeill, 2011) suggesting that examining data and connecting it to a claim requires in-depth thinking. Students who are new to the process of argumentation often struggle with identifying appropriate evidence and may not recognize the importance of supporting their ideas with evidence (Kuhn, 2010). In this study, students resorted to telling others to “Trust me, just trust me” or exclaiming, “I don’t know how to explain it!” as Xavier and Roman did when their peers pushed them to provide evidence to support their initial claims.
To encourage students to engage in argumentation the collaborative role of the Skeptic (Figure 20) was introduced in the second implementation (I-2). The rational was that the Skeptic by design, through a student continuously asking others to provide evidence for their thinking, would influence students’ engagement in argumentation. If examining the role of the Skeptic based on the sheer number of instances of argumentation then the role did not have an impact. The I-1 Female group, who did not utilize the Skeptic role, engaged in the most instances of argumentation. However, if examining the complexity of the arguments the students produced then the Skeptic was influential. The I-2 students had twice as many instances of argumentation where they provided evidence for their claim than the I-1 students; 26 instances compared to just 13. As noted earlier the I-2 students Asked for Evidence more frequently than the I-1 groups. Asking for Evidence was a part of the collaborative role description provided during the I-2 implementation.

**Skeptic** – It is your job to question and probe your group members for better evidence about their claims. **DO:** Demand evidence to support claims; ask questions to move the conversation forward. **DON’T:** Argue without good reason.

*Figure 20. Description of Skeptic role from Fall Compost curriculum.*

However, it is important to note that the majority of the Asking for Evidence questions were posed during the Making Observations (Card Sort) activity, the first activity in the curricular unit. The number of Asking for Evidence questions drops dramatically to only three asked during the What Factors? activity and zero asked during the final two activities. There were occasions where students demanded evidence or an explanation during the other activities; such as when Finn insisted that Roman provide him with an explanation during the Big Ideas about Ecosystems activity. However, students Asking for Evidence diminished as the implementation progressed. There could be several reasons for this occurrence, one of which is that the teacher
stopped reminding students about their collaborative roles during the I-2 implementation. Which then caused the students to stop using the roles in their groups.

**Cross-Case Analysis Summary.** In summary, the findings suggest the placement of the activity in the curricular unit and the design along with the structure of the activity seemed influenced the type of Inquiry/Science Content-focused questions students posed in their collaborative groups. The earlier the activity was in the curricular unit the more Inquiry/Science Content questions students posed. The information students were engaging with was new and therefore encouraged more curiosity and wonder early on in the unit. As time progressed and students became more comfortable with the content they did not need to ask as many Inquiry/Science Content focused questions.

Nonetheless, the structure of the activities seemed to have a greater influence on the type of Inquiry/Science Content question students asked than the placement of the activity. Each activity elicited different types of Inquiry/Science Content questions, however, all of the activities encouraged students to Seek clarification/explanation of another student’s idea. Students were quick to question each other and ask for an explanation if the information presented to the group was unclear. This action is indicative of being a good scientists and relates to students being critical consumers of the information they are presented by their peers and of science content.

Additionally, the Inquiry/Science Content questions also appeared to influence the arguments students engaged in during the Compost curriculum. The data suggests that the higher percentage of Inquiry/Science Content questions students asked, the more instances of argumentation that occurred. Though, just because the number of instances was high did not mean that all instances were equally complex. When students challenged each other, such as the
case during the *Carbon to Nitrogen* virtual experiment when Finn countered Roman’s claim about the 36:1 ratio having a different outcome due to the different materials used in the trial, the complexity of the argumentation increased. This finding suggests that providing students the opportunity to present and challenge each other’s ideas leads to more complex instances of argumentation as well as stronger arguments. This finding also suggests that the design of the activity is crucial, as students need the opportunity to disagree with one another for arguments to emerge.
CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS, & IMPLICATIONS

Summary of Findings

The goal of this study was to explore the relationship between student generated-questions and dialogic argumentation that emerged naturally during collaborative group work. This chapter summarizes and discusses the study topic and findings. The chapter concludes with implications for research and practice in science education.

The findings from this dissertation suggest that the questions students asked during collaborative segments related to and influenced students’ dialogic argumentation in their small groups. In general, as students posed more question, more instances of dialogic argumentation occurred among group members. The findings suggest that the type of student-generated question influenced the number and the complexity of the instance of argumentation during each activity. Specifically, the Inquiry/Science Content questions were identified as being more related to dialogic argumentation than the other types of student-generated questions.

The Inquiry/Science content questions were found to have sparked student discussion about the scientific concepts (e.g., decomposition, flow of energy) and indicated students’ points of confusion. On several occasions students such as Finn, Bayley, and Xavier expressed their confusion to the group and sought clarification of both science content and peers’ ideas. Other students, such as Charlotte, used the strategy of seeking confirmation of their ideas as a means to check their understanding of the science content. Furthermore, the Inquiry/Science Content
questions potentially instigated moments of deeper thinking about science content. These moments of deeper thinking occurred when students challenged and evaluated each other’s ideas and when students asked each other for evidence or an explanation. For example, during the *What Factors?* activity, Cedric used questions to evaluate Xavier’s research question about bacteria and decomposers. Likewise, Finn used questions to challenge Roman’s claim about air and plants using sunlight during the *Big Ideas about Ecosystems* activity. Moments like these demonstrate students’ use of Inquiry/Science Content questions to engage with the content, clarify points of confusion, and check each others’ understanding.

As discussed in Chapter Four, the sheer number of instances of argumentation alone does not provide researchers and educators with sufficient information about student engagement with and understanding of science content; instead, the complexity of students’ argumentation is essential to consider when investigating their learning about and understanding of scientific content and their development of scientific practices. Argumentation increased in complexity as students provided evidence, justification, and counter claims. As the complexity of an instance of argumentation increased, students wrestled with, and thought more deeply about, the science content. This deep learning is an important part of developing students’ comprehensive understanding of science since it encourages students to make connections (and/or disconnections) between ideas (Chin & Brown, 2000). The complexity of students’ dialogic argumentation was found to be linked to the specific types of Inquiry/Science Content questions: *Proposing potential research, Prompting a group member to share their idea, Asking for an explanation of an observed phenomena, Prompting group to extend their thinking, Seeking clarification/explanation of an idea, Asking for evidence, Seeking affirmation/confirmation of a concept, Seeking input on a concept.* As previously noted, certain Inquiry/Science content
questions (i.e., Seeking clarification/explanation of an idea, Asking for evidence) encouraged students to provide evidence for their thinking, as well as extend their explanations when needed.

**Discussion**

The data from this study shows that students’ questions helped them to navigate the science content presented in the Compost curricular unit. Students’ questions directed student thinking by enabling them to share their prior knowledge, identify points of uncertainty, challenge each others’ ideas, as well as generate and occasionally sustain increasingly complex instances of argumentation. In order to fully explore the phenomenon of how student-generated questions influenced their argumentation three sub-questions were established and addressed.

1. **a. In what ways does the number of questions asked during collaborative group work influence student development of arguments?**

The first sub-question focused on the sheer number of questions posed by students and the potential connection to their instances of argumentation. Data supported the notion that the more questions posed by a small group the more likely students had increased instances of argumentation. For example, the I-1 and I-2 Female groups asked the most questions and also had the most instances of argumentation. However, when examining the individual activities, there was not a distinct pattern relating the overall number of questions asked with the instances of argumentation. For instance, students asked the most questions during the virtual experiments; however, this activity was third in the number of instances of argumentation. This lack of a distinct pattern between the number of questions overall and students’ instances of
argumentation in the four activities led to the examination of the specific types of questions students posed during each activity (research question 1. b.).

1. b. How does the type of question posed in small group collaboration influence student dialogic arguments?

Five distinct categories of questions were identified during analysis: 1) Inquiry/Science content, 2) Social, 3) Defining the Task, 4) Materials Focused questions, and 5) Other. Of the five, only the Inquiry/Science Content questions were shown to be related to students’ instances of argumentation. As displayed in Table 25, the higher percentage of Inquiry/Science Content questions in an activity, the higher the number of instances of argumentation that were identified. Inquiry/Science Content questions are indicative of students’ natural curiosities about science content. This finding is supported by the existing literature. For example, Harper, Etkina, and Lin (2003) showed that the type of question, rather than the number, was an indicator of student conceptual understanding and achievement in physics. Likewise, Chin and Brown (2002) showed that certain types of questions influence student discourse and the co-construction of knowledge, thereby leading to deeper learning. Additionally, the current studies’ findings are reminiscent of those obtained by Chin and Osborne (2010a) who found that content focused wonderment questions stimulated student collaborative discourse and ultimately led to higher-quality arguments. However, the current study is unique in that it reflects students’ in the moment questions and instances of argumentation, an area that has not been readily studied.

As noted above, the Inquiry/Science Content questions had eight sub-categories that varied in their respective degrees of association to the frequency of instances of argumentation.
All four activities had a high number of Seeking clarification/explanation of another’s idea. The act of students requesting others to provide clarification or explanation inevitably prompted more discursive interactions among students. For example, during the Moisture virtual experiment, Bayley asked Alexa to clarify why they would conduct a trial without any water. Bayley’s need for clarification sparked a discussion between Alexa and Bayley about how moisture gets into a compost pile. Alexa explained to Bayley that even though they were not adding additional water to the virtual compost pile the added greens provided moisture for the compost. The Seeking clarification/explanation of another’s idea was the most prevalent of the Inquiry/Science Content questions, thus suggesting that it had a strong connection to students engaging in argumentation.

The second most prevalent type of question asked was Seeking input on a concept. These questions related directly to students’ queries and curiosities about the science content they were engaged with during an activity. In particular, these questions exposed students’ uncertainty and confusion about the content. For instance, during the Making Observations (Card Sort) activity Xavier asked, “So what’d y’all think this [holds up a card] should be?” Xavier was uncertain about the categorization of the card as either quantitative observation, qualitative observation or an inference and he sought help from his peers. This finding aligns with research conducted by Chin and Osborne (2010b), who showed that when students ask questions, they become more cognizant of what they do not know. Similarly, Chin and Osborne (2010b) found that content-focused questions enabled students to have extensive discussions about points of uncertainty.

The current study adds to current research because students utilized questions as metacognitive tools on their own due to no scaffolding or supports provided to students on how to question each other in collaborative groups. This finding suggests that students may have the ability to self-regulate their learning through their natural curiosities; as all questions posed by students
were those that students had in the moment as they worked to clarify their understanding. In summary, both Seeking clarification/explanation of another’s idea and Seeking input on a concept had strong connections to students’ frequency of instances of argumentation, often initiating an instance of argumentation as students expressed their uncertainty about science content.

1. c. How does the complexity of student arguments (claim, evidence, justification) relate to questions posed during collaboration?

The complexity of students’ instances of argumentation varied throughout the activities. Students were not provided with external scripts such as directives on how to engage in argumentation in their small groups, all instances of argumentation occurred naturally in their discourse. Complexity of arguments ranged from the presentation of a simple claim to a claim with evidence/justification along with a counterclaim with evidence/justification. When examining the more complex instances of argumentation, students often posed questions that Sought clarification/explanation of another’s idea. These type of questions encouraged students to explain their thinking further, which in many occasions meant they provided evidence or an explanation for their thinking. For example, the virtual experiments had the highest percentage of more complex arguments, with nearly 50% of the instances of argumentation identified as having a claim with at least evidence/justification presented. The virtual experiments also had the most Seeking clarification/explanation of another’s idea with 41 of these questions asked. This finding from the current study is encouraging and suggests a potential correlation between
students Seeking clarification/explanation of another’s idea and supporting claims with evidence/ providing justification.

Furthermore, Seeking clarification/explanation of another’s idea questions encouraged students to indicate their puzzlement, summarize their thinking, question opposing viewpoints, and evaluate each other’s ideas. These findings support work conducted by Chin and Osborne (2010b); who found that students’ questions acted as epistemic tools during student discourse that ultimately led to more sophisticated arguments. Moreover, the current study extends previous research because students posed questions and constructed arguments with limited external scripts which is unique in this area of research.

Likewise, another type of Inquiry/Science Content question, Asking for evidence, encouraged students to engage in more complex instances of argumentation. The Making Observations (Card Sort) activity had 13 higher-complexity instances of argumentation along with 18 Asking for Evidence questions, the most Asking for Evidence questions of any activity. The design of the Making Observations (Card Sort) activity enabled students to readily make claims about the qualitative and quantitative observation and inference cards. For instance, Finn asked, “Yeah, quan…but how do you know?” after Roman suggested that a card should be categorized as a quantitative observation. Typically, as in the previous example about Finn and Roman, students provided evidence, justification, or an explanation of their thinking.

The I-2 groups had the collaborative role of Skeptic, which was designed for students to ask for evidence from their group mates. The use of the Skeptic role during collaborative work led the I-2 groups to ask 14 of the 18 Asking for Evidence questions, during the Making Observations (Card Sort) activity. This finding suggests that the role of the Skeptic was influential during this activity and that it potentially has a connection to students generating more
complex instances of argumentation. Nevertheless, *Asking for Evidence* dropped dramatically in the following activities for both I-1 and I-2 groups, with only three questions of this type asked during the *What Factors?* activity and none in the final two activities. The decline in emphasis on the collaborative roles could explain the drop in *Asking for Evidence questions* as the curricular unit progressed. In the *Making Observations (Card Sort)* activity the teacher not only emphasized the collaborative roles, but also discussed how the students should enact the collaborative roles in their small groups. This, however, was not the case as the implementations progressed. Students were reminded of the collaborative roles, and that they should be using the collaborative roles, but there was little to no discussion on how to enact the roles during the activities. The reduced emphasis on the expectations of how to utilize the collaborative roles, specifically the role of the Skeptic, could have been a factor in the reduction of *Asking for Evidence* questions.

**Conclusions**

This study has demonstrated that students’ questions are an important scientific practice and relate to the development of students’ argumentation skills. Students frequently used questions to indicate points of confusion or to seek clarification of ideas and content material. Students also encouraged each other to explain their thinking as well as to provide more information about a given topic. These spontaneous questioning interactions among students during collaborative segments revealed students’ knowledge building processes and their ability to reconcile new information with their existing understanding of science content (Scardamalia & Bereiter, 1992). Students’ explanations did not always include evidence to support the initial claim; however, the explanations showed that students were capable of reasoning about science content and expressing their understandings.
This study suggests that the type of Inquiry/Science Content questions students posed during the four activities influenced students’ argumentation patterns. Although not all instances of argumentation resulted in complete, well-structured and scientifically accurate arguments, the students were able to participate in the act of constructing dialogical arguments. The students were not provided with external scripts, such as scaffolding on how to argue, but were able to successfully (on a few occasions) present coherent ideas with valid evidence as support. It is important to note that the goal of the Compost curriculum was not for students to engage in dialogical argumentation; rather, the goal was for students to work collaboratively to complete the designed tasks. All instances of argumentation arose from student curiosity and the need for further explanation or reconciliation of conflicting information. Students proposed, evaluated, and critiqued each other’s ideas with regards to the science content (Berland & Lee, 2012; Berland & Reiser, 2009); thus making them critical consumers of science, a goal identified in The Framework for K-12 Science Education (NRC, 2012).

Unlike other studies (e.g., Chin & Osborne, 2010b; Cuccio-Schirripa & Steiner, 2000; Keys 1998), students in this dissertation study were not provided an abundance of scaffolds or supports for generating questions or engaging in argumentation. For instance, Chin and Osborne (2010b) required students to generate questions with teacher guidance in the first phase of their study; these student-generated questions became the focus of student talk during group discussions in subsequent phases. The only external structural supports for generating questions in this dissertation study were the three question prompts provided in the What Factors? activity. These prompts gave students examples of researchable questions, so they could create their own questions. These prompts were provided due to the expectation that students would be conducting research in the Vidyamap and needed to generate researchable questions in order to
achieve this goal. In the current dissertation study, students’ questions emerged naturally during group discussion as they navigated the different activities. These were students’ in-the-moment curiosities that happened throughout the Compost curricular unit.

Similarly, students were provided minimal support for engaging in argumentation. The four activities each had nominal embedded language that encouraged students to provide evidence for their thinking when they responded to the written questions. The instructions for responding to questions included language like “provide an explanation for your thinking” or “include evidence to support your thinking.” Students in both implementations were exposed to the use of the word “evidence” in this manner as they engaged with the Compost curricular unit. Other specialized argumentation language, such as the development of “counter claims”, “providing reasoning”, or “justification,” was not utilized in the Compost curriculum. All instances of students providing claims and reasoning or justification that occurred during student discourse happened naturally.

Questions also helped students to participate in knowledge integration. The I-1 Female group frequently shared their thoughts as they wrote their ideas during the Think segments of each activity. The girls then used these thoughts as jumping off points for their Collaborate discussions. For example, after Bayley shared her writing from the Think segment in the Big Ideas about Ecosystems activity, Nia questioned the inclusion of the science terms abiotic and biotic factors. Bayley provided a brief explanation, prompting Alexa to incorporate the terms into the group’s collaborative response. In each activity, each girl brought discrete pieces of knowledge that allowed the group to construct a more coherent response based upon each of their individual knowledge pieces. The use of questions to prompt each other to share ideas allowed the students to build internal associations between and among new knowledge and to
reconcile differences with existing knowledge (Chin & Brown, 2002). Prompting to share ideas and the evaluation of ideas were critical parts of the knowledge integration process across all groups examined in this study.

Finally, this study suggests that the design, structure, and goals of each activity influenced the type of Inquiry/Science Content questions students posed and the number and complexity of their instances of argumentation. The activities that were designed to promote student discussion and specifically disagreement, like the Making Observations (Card Sort) activity, the more frequently students questioned each other and engaged in argumentation.

**Strengths & Limitations**

As previously noted, there are limitations to this research. However, the most prominent limitation of this research could also be considered one of its strengths. This study was an in-depth analysis of a single school site, which provided a glimpse into an isolated setting; therefore, generalizations cannot be made, a noted limitation. Yet, the student population was ethnically diverse and lived in a rural context; thus, this study provides important insight into this specific learning environment. This work will need to be expanded, both to different contexts in order to make broader generalizations about student-generated questions and argumentation. An additional strength about this study is that the teacher was consistent in his implementation for both the I-1 and I-2 groups. This allowed for a strong basis for comparison across implementations.

Other strengths and limitations have to do with the structure and design of the Compost curriculum. The curriculum provides a specific context within which students worked. They were provided collaborative structures to help them work as a group to accomplish the tasks outlined by the curricular unit. The macroscripts of the curriculum influenced how students
approached the tasks and therefore influenced the questions students posed and the instances of argumentation that emerged. This can be contrasted with other studies that have examined asking questions and engaging in argumentation individually. The majority of research examining questioning patterns of students (e.g. Chin & Osborne, 2010a, 2010b; Cuccio-Schirripa & Steiner, 2000; Keys, 1998; Marbach-Ad & Sokolove, 2000) provided students with supports for how to ask science related questions, specifically researchable and investigable questions. These studies also focused on the questions that students wrote down, and not what they spoke verbally. This study differs from previous work in that it demonstrates students’ innate curiosities and how those curiosities influence their ability to engage in argumentation.

**Implications**

**Implications for Practice.** The National Research Council (NRC, 2012) outlined the eight scientific practices as a means to establish a way for teachers to engage students in the discourses of science. This study focused on two identified scientific practices, *Asking questions* and *Engaging in argument from evidence*, leading to several implications for practice. First, it is essential to allow students to ask questions and to wonder about science phenomenon within classroom science experiences. With the embedded Think-Collaborate-Share cycles in the Compost curriculum students were provided time to ponder and engage with science content. Ensuring that students are given ample opportunity to work through and question their understanding of science content is integral for learning. Humans are naturally curious about the world around them and this curiosity has led to many scientific discoveries. The NRC (2012) identifies Asking questions as being essential to developing students’ scientific habits of mind. It also notes that being able to ask good questions helps students become critical consumers of scientific knowledge. The students in this study frequently questioned and were critical of the
information provided by their peers. Giving students the opportunity and the freedom to express their uncertainties is an important part of science learning.

As described earlier, the Compost curriculum was not designed to foster student questions, nor engage them in argumentation but these two scientific practices occurred naturally as students engaged with the curricular material. The findings show that students are naturally curious and will question themselves, their peers, and the science content if they do not understand what is being presented. This is important because science education literature often focuses on how students need direct instruction or significant scaffolding in order to participate in the scientific practices. These findings suggest that students may not need as much direct support but need the development of classroom norms that foster an inquisitive and argumentative environment.

Additionally, studies (e.g., Beyer & Davis, 2008; Larrain, Freire, & Howe, 2014; McNeill & Pimentel, 2010; Newton et al., 1999) have found that teachers struggle to implement argumentation with their students. Implementing dialogical argumentation in the science classroom often requires teachers to undergo a pedagogical shift from a more teacher-directed to a student-centered form of instruction (Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). This study demonstrates that a structured activity, such as the ones utilized in the Compost curriculum, along with the opportunity for students to engage in small group conversations enable aspects of argumentation among students. Therefore, teachers do not have to be argumentation experts to utilize it in their classrooms. Teachers, however, do need to be supportive of students sharing their ideas, disagreeing with one another, and working through their understanding in collaborative groups. The inclusion of the Think-Collaborate-Share cycles throughout the Compost curriculum provided students time during each activity to work through
the task as an individual, and as a group thus fostering a variety of questions and instances of argumentation.

The findings suggest that teachers utilizing the Compost curriculum in their classroom be supported in generating classroom norms that support student queries and the discussion of all ideas. As the data demonstrates, students can and do engage in questioning practices and some aspects of dialogical argumentation. By generating classroom norms that encourage these science practices, students become the dominant voice in the classroom and their input becomes valued discourse. Providing students with more autonomy and ownership of their learning could increase their science and inquiry questions as well as support their engagement in argumentation. This suggestion supports the notion that students need the opportunity to express their thinking and understanding of science content among their peers. In order for students to have an opportunity to grapple with scientific phenomenon, teacher-directed instruction should be limited in science classrooms. The more students engage in and with scientific practices the more they will develop these skills as well as grow their conceptual understanding of science content.

**Implications for future research.** This study focused on the spontaneous questions and dialogical instances of argumentation that students engaged in during a specific curricular implementation. The curriculum was not designed to foster student questions and argumentation, yet these scientific practices emerged as students interacted with the curricular unit. Several other forms of inquiry activities are in the curricular unit but were not examined for this study. Further exploration of the curriculum, the types of questions, and the instances of argumentation that emerge could support the findings of this study. The interactive activities, like the virtual experiments and the *Making Observations (Card Sort)* activity, provided students with ample
opportunities to express their curiosity. Examining additional activities with similar structures as these two activities should result in similar findings. Additionally, implementing and studying student discourse in a different setting could also provide insight into how asking questions influences argumentation. Additional research sites would help to bolster and support the findings from this study.

Another direction for future research would be to look at the individual students’ contributions to each group’s discourse. As noted in the development of the four cases, there was at least one individual in each group who asked more questions than their group mates. Further analysis of the types of questions these students posed and how many instances of argumentation they engaged in could provide insight into collaborative practices and how individuals influence the overall discourse and learning of a group. The findings from this type of study could then inform practice as it would help teachers in group formation for optimal collaborative discourse.

In summary, the National Research Council identified eight scientific practices that all students need to develop in order to fully engage in the discourses of science. These practices do not occur in isolation but are intentionally designed to overlap in order to avoid the impression that there is only one approach to science (NRC, 2012). Yet, past science education research has mainly focused on individual scientific practices and more research needs to be done to explore how the practices influence one another in the classroom. This study explored and the findings suggest that asking questions, an essential scientific practice, relates to and influences student dialogic argumentation in collaborative groups. In conclusion, the types of questions students ask matter with regards to dialogic argumentation. In order to support students in asking questions that lead to complex instances of argumentation, activities need to be designed and structured to enable students to participate in these endeavors. Additionally, classroom norms need to be
established to encourage and foster students’ natural curiosity and autonomy during scientific investigations.
Activity 4: Making Observations

There are many kinds of interesting observations you can make of your compost over time:

**Quantitative** observations are ones that describe quantity or numbers. Temperature is a quantitative measurement because we can measure it using an established scale, such as Fahrenheit or Celsius, and we know what 76 degrees F means.

Some other quantitative measurements that can be taken are height, weight, density, pH level, and moisture content.

**Qualitative** observations are ones that describe the quality or characteristics of things. Something can look or feel fuzzy, hard or sharp, or smell like cookies, or taste sweet.

Example: Image of fuzzy part of a jacket

Think about the differences between observations and inferences:

**Observations** are descriptions of what we notice. They consist of factual information that can be gathered by using our five senses and scientific tools.

**Inferences** are based on observations, but they take things a step further to draw conclusions about the data that has been collected.

For example, if you have observed that your friend has a dog, three cats, and five lizards, and that she often mentions that she loves to go to the pet store, you can infer that your friend is a pet lover.

With your team

Think about the kinds of observations and data you want to keep track of to monitor changes and patterns in your compost.
Activity 4: Making Observations

Card Sorting
Using the cards provided, divide them equally among group members. Keeping out the cards labeled: Qualitative observation, Quantitative observation, and Inference.

Think
On your own think about whether each of the cards you have is a Qualitative observation, Quantitative observation, or an Inference.

Collaborate
With your group discuss and sort all of the cards according to whether you think each card represents a Qualitative observation, Quantitative observation or an Inference. Use the chart on the next page to record your thinking.

In your small group, do the following:

• Choose your role.
  o Discussion Director – You are responsible for guiding and keeping your group on each task. You will need to keep your group moving forward, but also make sure that your group is being thoughtful. All voices in your group need to be heard.
  o Reporter – You are responsible for recording the group's ideas and being prepared to share the ideas with the whole class.
  o Starter – You are responsible for getting the discussion started! You share your ideas first. If there are materials or technology involved you are in charge of those elements.

• Discuss your thinking.
  o Using the roles above to guide you, discuss your individual thinking about the question above.
  o Everyone is responsible for discussing and sharing out her/his ideas with the group.
Your group’s reporter shares the ideas from your collaboration with the whole class.

Your group’s reporter shares the ideas from your collaboration with the whole class. As you listen to the other groups, think about the following questions:

- What different ideas were shared in other groups?
- Do you agree with everything that was shared? Why or why not?
- Did anything that was shared make you think differently?
Activity 4: Making Observations

There are many kinds of interesting observations you can make of your compost over time:

**Quantitative** observations are ones that describe quantity or numbers. Temperature is a quantitative measurement because we can measure it using an established scale, such as Fahrenheit or Celsius, and we know what 76 degrees F means.

Some other quantitative measurements that can be taken are height, weight, density, pH level, and moisture content.

**Qualitative** observations are ones that describe the quality or characteristics of things. Something can look or feel fuzzy, hard or sharp, or smell like cookies, or taste sweet.

Example: Image of fuzzy part of a jacket

**With your team**

Think about the kinds of observations and data you want to keep track of to monitor changes and patterns in your compost.

**Scientists often make observations to collect data for their experiments. These observations are a record of what happened and allow us to analyze the data!**

**Hints and Tips!**

**Think about the differences between observations and inferences:**

**Observations** are descriptions of what we notice. They consist of factual information that can be gathered by using our five senses and scientific tools.

**Inferences** are based on observations, but they take things a step further to draw conclusions about the data that has been collected.

For example, if you have observed that your friend has a dog, three cats, and five lizards, and that she often mentions that she loves to go to the pet store, you can infer that your friend is a pet lover.
Making Observations

Card Sorting
Using the cards provided, divide them equally among group members. Keep out the cards labeled: Qualitative observation, Quantitative observation, and Inference.

Think
On your own think about whether each of the cards you have is a Qualitative observation, Quantitative observation, or an Inference.

Collaborate
With your group discuss and sort all of the cards according to whether you think each card represents a Qualitative observation, Quantitative observation or an Inference. Use the chart on the next page to record your thinking.

Use the following collaborative roles to help you work through the activity.

- Choose your role.
  - **Discussion Director** – You are responsible for guiding and keeping your group on each task. **DO:** Get things started, be a problem solver, keep the goal in mind (stay on topic), make sure all voices are heard – Fair and equitable contributions. **DON’T:** Dominate the conversation, or let things get off track.
  - **Reporter** – You are responsible for recording the group’s ideas and being prepared to share the ideas with the whole class. **DO:** Be ready to update the teacher if they visit, take notes of important ideas that are discussed. **DON’T:** Just write and forget to talk/discuss/contribute to the conversation.
  - **Skeptic** – It is your job to question and probe your group members for better evidence about their claims. **DO:** Demand evidence to support claims; ask questions to move the conversation forward. **DON’T:** Argue without good reason.
  - **EVERYONE** – **DO:** Bring ideas, think critically, stay on topic, actively participate, and push thinking forward, talk/interact respectively.
Share

Time for a Whole Class Discussion, your group will Share their findings with the class. Use this opportunity to learn from others.

As you listen to the other groups, think about the following questions:

- What different ideas were shared in other groups?
- Do you agree with everything that was shared? Why or why not?
- Did anything that was shared make you think differently?
<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Qualitative</th>
<th>Excited</th>
<th>Multi-colored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple 4 inches</td>
<td>Color</td>
<td>4000 m</td>
<td>Circular</td>
</tr>
<tr>
<td>Hard</td>
<td>Texture</td>
<td>80 Degrees</td>
<td>Weak</td>
</tr>
<tr>
<td>Small, Long</td>
<td>Muscular</td>
<td>30 cm</td>
<td>6-9 inches</td>
</tr>
<tr>
<td>Long</td>
<td>Mass</td>
<td>My cell phone case is pink</td>
<td>Sticky</td>
</tr>
<tr>
<td>Heavy</td>
<td>Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behavior</td>
<td>Mass</td>
<td>The plant grew 3 inches this week.</td>
<td>It is cold today; it is probably going to snow</td>
</tr>
<tr>
<td>Sound</td>
<td>Temperature</td>
<td>It smells like cookies, so mom must be baking.</td>
<td>The 20 meter high tree has no leaves on it.</td>
</tr>
<tr>
<td>Fuzzy</td>
<td>Bumpy and Black</td>
<td></td>
<td>After the meeting, 10 people left the room</td>
</tr>
<tr>
<td>She is carrying her umbrella so it must be raining outside.</td>
<td>The customer did not finish his meal – he must be full.</td>
<td>The girl’s hair was very curly.</td>
<td>The road to my house is very curvy.</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>---------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>It is 40 degrees Celsius outside.</td>
<td>The white couch has 3 cushions on it.</td>
<td>The desktop is smooth.</td>
<td>The girl is smiling because she must have done well on her test.</td>
</tr>
<tr>
<td>It took 12 minutes for the train to come.</td>
<td>The man is running because he must be late to work.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The boy is crying because he must have hurt himself.</td>
<td>The math homework had 25 questions on it.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inference</td>
</tr>
</tbody>
</table>
Activity 8: What factors help decomposers break down matter?

When we did our trash investigation (Activity 5) you were able to determine what types of waste break down (organic) and what types of waste don't (inorganic). You have already created bio-reactors to begin observing how matter decomposes in compost. Your challenge for the unit is to propose a composting system that breaks down organic waste quickly. Now let’s think about what factors help decomposers in compost break down matter.

On your own, think about the prompt below

What factors do you think help decomposers in compost break down matter?

____________________________________________________
____________________________________________________
____________________________________________________

In your group, share your individual ideas about the factors that help decomposers in compost break down matter.

____________________________________________________
____________________________________________________
____________________________________________________

Your group’s reporter shares the ideas from your collaboration with the whole class. As you listen to the other groups, think about the following questions:
• What different ideas were shared in other groups?
• Do you agree with everything that was shared? Why or why not?
• Did anything that was shared make you think differently?
Activity 8: What factors help decomposers break down matter?

Our Team’s Questions
After your brainstorm, each group member needs to write at least one question to guide your research on VidyaMap about the factors that help decomposers to break down organic materials.

In the box below there are question stems to help you get started.

How does __________ help in decomposition?
Does organic material need __________ in order to decompose into compost?
What are the abiotic factors that help decomposers break down organic material?

Think Like Scientists and Engineers!
Questions guide all scientific and engineering investigations. Asking questions helps scientists and engineers to gather evidence for:

- creating and refining models
- generating explanations
- challenging their current understanding of the science

Question 1:

Question 2:

Question 3:

Question 4:

Question 5:
APPENDIX D: IMPLEMENTATION 2 – WHAT FACTORS? ACTIVITY

What factors help decomposers break down matter?

When we did our trash investigation (pg. 15-19) you were able to determine what types of waste break down (organic) and what types of waste don’t (inorganic). Now let’s think more about the factors that help decomposers break down matter.

Think about it:

You have already created bio-reactors to begin observing how matter decomposes in compost. You have been collecting quantitative data about your compost.

- What do these measurements mean?
- What do they tell you about the decomposition of your compost?
- What are decomposers breaking down? How?
- How are matter and energy changing during decomposition?

What factors do you think help decomposers in compost break down organic matter?

____________________________________________________

____________________________________________________

____________________________________________________

____________________________________________________

____________________________________________________

____________________________________________________

____________________________________________________
What factors help decomposers break down matter?

Let’s delve deeper into the process of decomposition, previously you identified factors that aid in the decomposition of matter. As a class we will generate questions to help guide our research.

In the box below there are question stems to help you get started.

How does _________ help in the decomposition of matter?
What are _______ and how do they aid in the decomposition of matter?
What are the abiotic factors that help decomposers break down organic matter?

Think Like Scientists and Engineers!
Questions guide all scientific and engineering investigations. Asking questions helps scientists and engineers to gather evidence for:

- creating and refining models
- generating explanations
- challenging their current understanding of the science

Question 1:

________________________________________________________________________

________________________________________________________________________

Question 2:

________________________________________________________________________

________________________________________________________________________

Question 3:

________________________________________________________________________

________________________________________________________________________

Question 4:

________________________________________________________________________

________________________________________________________________________

Question 5:

________________________________________________________________________
Activity 15: Investigating Moisture in Your Compost

- Does your compost have any moisture (water) in it?
- Could the amount of moisture affect the rate at which your compost is breaking down?
- Could it cause your compost to smell nasty or cause a lot of mold to grow in your bio-reactor?

Virtual Experiment
In the compost moisture simulation, you will investigate how moisture affects how quickly organic materials break down in a compost.

Getting ready to conduct your experiment!

On your own

Make some predictions about how moisture might affect the decomposition process:

Prediction:
The amount of moisture in compost affects decomposition of organic matter because;
water (circle all that apply)

fills in spaces between compost materials
affects circulation of Oxygen
creates aerobic or anaerobic conditions

Why do you think this? Explain your reasoning.

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
Activity 15: Moisture Virtual Experiment

What is the optimal amount of moisture for breaking down organic materials in a compost pile?

Your challenge in this moisture exploration is to figure out the ideal amount of moisture in compost to promote decomposition. This will help you to understand what will happen to your compost if moisture conditions are not the best.

Sources of Moisture in Compost
- Greens
- Added water

<table>
<thead>
<tr>
<th>Material Category</th>
<th>Common home composting materials</th>
<th>Moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greens</td>
<td>Fruit and vegetable scraps, grass clippings</td>
<td>75%</td>
</tr>
<tr>
<td>Brown 1</td>
<td>Dry fallen leaves</td>
<td>0%</td>
</tr>
<tr>
<td>Browns 2</td>
<td>Oats, wheat, straw</td>
<td>0%</td>
</tr>
<tr>
<td>Browns 3</td>
<td>Cardboard, paper, newspaper, wood chips, saw dust</td>
<td>0%</td>
</tr>
</tbody>
</table>

Use the chart on the next page to keep track of the moisture simulations you conduct.

Note: In the upcoming experiment, the compost mixture you will experiment with has an ideal balance of carbon to nitrogen. This is a controlled variable in the experiment to help you know what is actually affecting the results of the experiment.
## Activity 15: Moisture Virtual Experiment

<table>
<thead>
<tr>
<th>Independent / Manipulated Variable</th>
<th>Dependent / Responding Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>% Moisture</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>What was the result of trial 1? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
<tr>
<td>2</td>
<td>What was the result of trial 2? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
<tr>
<td>3</td>
<td>What was the result of trial 3? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
</tbody>
</table>

Collaborate
### Activity 15: Moisture Virtual Experiment

<table>
<thead>
<tr>
<th>Independent / Manipulated Variables</th>
<th>Dependent / Responding Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial % Moisture</td>
<td>Rate of decomposition</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>What was the result of trial 4? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>What was the result of trial 5? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
<tr>
<td><strong>6</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>What was the result of trial 6? Was decomposition successful? Explain how you know:</td>
</tr>
<tr>
<td></td>
<td>How could you change the amount of moisture to get a better result? Explain why you think this:</td>
</tr>
</tbody>
</table>
Activity 15: Moisture Virtual Experiment Continued

1. How does moisture affect how organic materials break down in compost?

   We found that:
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   ________________________________
   
   We know this because (refer back to your data chart):
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   ________________________________

2. We think the ideal % moisture is: _____________

   We know this because (refer back to your data chart):
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   ________________________________

Share Your group’s reporter should post a note on your class’s Virtual Collaboration Board that shares what you learned from this simulation.
APPENDIX F: IMPLEMENTATION 2 – CARBON TO NITROGEN RATIO
VIRTUAL EXPERIMENT

Carbon to Nitrogen Ratio in your Compost

**Ratio:** The different materials you put in your compost bio-reactor have different amounts of carbon and nitrogen in them.

- The balance of carbon and nitrogen contained in the organic materials you put into your compost can have a significant impact on decomposer growth and how quickly your compost will break down.
- This balance is called the Carbon to Nitrogen Ratio (C:N Ratio)

**Fun Science Information about carbon and nitrogen!**

**Carbon** and **Nitrogen** are two of the most common elements on earth.

Bacteria in compost get their energy to live and grow from the **carbon** structures in organic materials.

**Nitrogen** is a crucial component in compost for bacteria to support their cell growth and functioning.

**What do you know about matter and elements?**

Did you know that carbon and nitrogen are two different types of elements?

- Elements are the building blocks of all matter.
- Elements are different from each other because they contain a different number and arrangement of particles.
- Everything around you is made up of elements.
Carbon to Nitrogen Ratio Virtual Experiment Preparation

Getting ready to conduct your experiment!

<table>
<thead>
<tr>
<th>Learn your Compost Lingo!</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What’s the deal with using the terms “greens” and “browns” when making compost?</strong></td>
</tr>
<tr>
<td>Many of the organic materials that contain a lot of carbon, like dead leaves and wood chips, are brown in color. So instead of talking about carbon-rich organic materials, people refer to these as the “browns” in compost.</td>
</tr>
<tr>
<td>On the other hand, many of the organic materials that contain relatively more nitrogen, like grass clippings and vegetable wastes are green in color. This is why nitrogen-rich materials are called “greens!”</td>
</tr>
</tbody>
</table>

Please Note!! All organic materials contain both carbon and nitrogen; it is just that some materials have a lower or higher carbon or nitrogen ratio than others.

On your own:

Make a prediction about how carbon and nitrogen affect the decomposition process:

**Prediction:**
Which ratio of carbon to nitrogen do you predict will be best for your decomposers and promote decomposition? Circle one ratio below:

<table>
<thead>
<tr>
<th>~80:1</th>
<th>~30:1</th>
<th>~15:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A lot more carbon than nitrogen</td>
<td>More carbon than nitrogen</td>
<td>A little more carbon than nitrogen</td>
</tr>
</tbody>
</table>

Explain why you think this:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
### Carbon to Nitrogen Ratio Virtual Experiment

<table>
<thead>
<tr>
<th>Trial</th>
<th>Independent / Manipulate Variable</th>
<th>Contents of compost</th>
<th>Dependent / Responding Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon: Nitrogen</td>
<td></td>
<td>Rate of decomposition</td>
</tr>
<tr>
<td>1</td>
<td>Greens: _____ g</td>
<td>Browns 1: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 2: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 3: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td>What was the result of trial 1?</td>
<td></td>
<td>Was decomposition</td>
</tr>
<tr>
<td></td>
<td>successful? Explain how you</td>
<td></td>
<td>successful? Explain</td>
</tr>
<tr>
<td></td>
<td>How could you change the</td>
<td></td>
<td>why you know:</td>
</tr>
<tr>
<td></td>
<td>carbon:nitrogen ratio to get a</td>
<td></td>
<td>better result? Explain</td>
</tr>
<tr>
<td></td>
<td>better result? Explain why you</td>
<td></td>
<td>why you think this:</td>
</tr>
<tr>
<td>2</td>
<td>Greens: _____ g</td>
<td>Browns 1: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 2: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 3: _____ g</td>
<td></td>
</tr>
<tr>
<td></td>
<td>What was the result of trial 2?</td>
<td></td>
<td>Was decomposition</td>
</tr>
<tr>
<td></td>
<td>successful? Explain why or why</td>
<td></td>
<td>successful? Explain</td>
</tr>
<tr>
<td></td>
<td>not:</td>
<td></td>
<td>why or why not:</td>
</tr>
<tr>
<td></td>
<td>How could you change the carbon:</td>
<td></td>
<td>better result? Explain</td>
</tr>
<tr>
<td></td>
<td>nitrogen ratio to get a better</td>
<td></td>
<td>why you think this:</td>
</tr>
</tbody>
</table>

Collaborate
<table>
<thead>
<tr>
<th>Trial</th>
<th>Contents of compost</th>
<th>Rate of decomposition</th>
<th>Temperature</th>
<th>Odor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Greens: __________g</td>
<td>Browns 1: __________g</td>
<td>Browns 2: __________g</td>
<td>Browns 3: __________g</td>
<td>What was the result of trial 3? Was decomposition successful? Explain why or why not:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Greens: __________g</td>
<td>Browns 1: __________g</td>
<td>Browns 2: __________g</td>
<td>Browns 3: __________g</td>
<td>What was the result of trial 4? Was decomposition successful? Explain why or why not:</td>
</tr>
</tbody>
</table>

How could you change the carbon:nitrogen ratio to get a better result? Explain why you think this.
<table>
<thead>
<tr>
<th>Trial</th>
<th>Carbon: Nitrogen</th>
<th>Contents of compost</th>
<th>Rate of decomposition</th>
<th>Temperature</th>
<th>Odor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td>Greens: ______ g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 1: ______ g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 2: ______ g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Browns 3: ______ g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>How could you change the carbon:nitrogen ratio to get a better result? Explain why you think this.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What was the result of trial 5? Was decomposition successful? Explain why or why not:

| 6     |                  | Greens: ______ g    |                      |             |      |          |
|       |                  | Browns 1: ______ g  |                      |             |      |          |
|       |                  | Browns 2: ______ g  |                      |             |      |          |
|       |                  | Browns 3: ______ g  |                      |             |      |          |
|       |                  |                      | How could you change the carbon:nitrogen ratio to get a better result? Explain why you think this. |

What was the result of trial 6? Was decomposition successful? Explain why or why not:
Carbon to Nitrogen Ratio Virtual Experiment Continued

Report Out!

1. We think the ideal carbon to nitrogen ratio range in our model compost is:

   - We know this because (refer back to your data):


2. Which of the following cause-and-effect chains best shows how the C:N ratio in compost affects how decomposers break down organic materials in compost? Circle one option under each part of the chain (C:N ratio, air circulation, decomposer health, etc.) and draw arrows between each of your choices to create a cause-and-effect chain that makes the most sense. There can be more than one correct causal chain.

<table>
<thead>
<tr>
<th>C:N Ratio</th>
<th>Air Circulation</th>
<th>Decomposer Health</th>
<th>Temperature for Decomposers</th>
<th>Decomposition Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (~80:1)</td>
<td>Aerobic</td>
<td>Decomposers will have enough energy and will grow</td>
<td>too cold</td>
<td>Fast</td>
</tr>
<tr>
<td>Medium (~30:1)</td>
<td>Anaerobic</td>
<td>Decomposers will not get enough energy to live</td>
<td>appropriate</td>
<td>Slow</td>
</tr>
<tr>
<td>Low (~15:1)</td>
<td></td>
<td>Decomposers will not have enough nitrogen to grow</td>
<td>too hot</td>
<td></td>
</tr>
</tbody>
</table>

Use data from your experiment to provide evidence for why you think this:
Activity 36: Big Ideas about Ecosystems

Think back to your group’s investigation of your own ecosystem, and what you have learned about the relationships between biotic and abiotic factors by monitoring your own compost. Let’s discuss what we have learned about what it means for something to be an ecosystem!

First, discuss with your group. Then, be prepared to explain your ideas to the class and support them with evidence!

Scientists use their data and research to make statements about how they think the world works. When you make a statement or give an explanation, you must back it up with evidence to convince others!

Take notes about the ideas your class agrees on in the space below.
APPENDIX H: IMPLEMENTATION 2 – BIG IDEAS ABOUT ECOSYSTEMS ACTIVITY

Big Ideas about Ecosystems

Think back to your group's investigation of your own ecosystem, and what you have learned about the relationships between biotic and abiotic factors by monitoring your own compost. Let's discuss what we have learned about what it means for something to be an ecosystem!

First, discuss with your group. Then, be prepared to explain your ideas to the class and support them with evidence!

Scientists use their data and research to make statements about how they think the world works. When you make a statement or give an explanation, you must back it up with evidence to convince others!

In your group's investigation of your ecosystem what did you learn about the interaction of abiotic and biotic factors?
____________________________________________________________________
____________________________________________________________________

What did you learn about the interactions between decomposers, producers, and consumers?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

Do your responses to the above questions match the cycling of matter occurring within your compost?
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
## APPENDIX I: CATEGORIES OF QUESTIONS

<table>
<thead>
<tr>
<th>Major Category</th>
<th>Sub-Category</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inquiry/Science Content-Focused</strong></td>
<td>Proposing potential research</td>
</tr>
<tr>
<td></td>
<td>Prompting group member to share their idea</td>
</tr>
<tr>
<td></td>
<td>Asking for an explanation for an observed phenomena</td>
</tr>
<tr>
<td></td>
<td>Prompting group to extend thinking</td>
</tr>
<tr>
<td></td>
<td>Seeking clarification/explanation of another students’ idea</td>
</tr>
<tr>
<td></td>
<td>Asking for evidence</td>
</tr>
<tr>
<td></td>
<td>Seeking affirmation/confirmation of a concept</td>
</tr>
<tr>
<td></td>
<td>Seeking input on a concept</td>
</tr>
<tr>
<td><strong>Defining the Task</strong></td>
<td>Asking for help</td>
</tr>
<tr>
<td></td>
<td>Establishing collaborative roles</td>
</tr>
<tr>
<td></td>
<td>Checking progress of the group</td>
</tr>
<tr>
<td></td>
<td>Orienting self to task</td>
</tr>
<tr>
<td></td>
<td>Seeking permission from group members</td>
</tr>
<tr>
<td></td>
<td>Directing group’s attention</td>
</tr>
<tr>
<td></td>
<td>Refocusing peer/group</td>
</tr>
<tr>
<td></td>
<td>Defining the Task</td>
</tr>
<tr>
<td><strong>Materials-Focused</strong></td>
<td>Asking for clarification</td>
</tr>
<tr>
<td></td>
<td>Asking how to use materials</td>
</tr>
<tr>
<td></td>
<td>Negotiating access to materials</td>
</tr>
<tr>
<td></td>
<td>Checking availability of materials</td>
</tr>
<tr>
<td></td>
<td>Reading questions verbatim</td>
</tr>
<tr>
<td></td>
<td>Expressing frustration with materials</td>
</tr>
<tr>
<td><strong>Social</strong></td>
<td>Social talk</td>
</tr>
<tr>
<td></td>
<td>Self talk</td>
</tr>
<tr>
<td></td>
<td>Establishing hierarchy of group</td>
</tr>
<tr>
<td></td>
<td>Social talk with authority</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Seeking help from authority</td>
</tr>
<tr>
<td></td>
<td>Huh?</td>
</tr>
<tr>
<td></td>
<td>Offering help</td>
</tr>
<tr>
<td></td>
<td>Asking about language</td>
</tr>
</tbody>
</table>
REFERENCES


