AN EXAMINATION OF TEACHER QUESTIONING AND STUDENT RESPONSES WITHIN THE CONTEXT OF AN INTEGRATED STEM PROJECT

A Capstone Project

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Christopher Dittrick, M.Ed., B.A.

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Christopher Dittrick
Curriculum, Instruction, and Special Education
Curry School of Education and Human Development
University of Virginia
Charlottesville, Virginia

APPROVAL OF THE CAPSTONE PROJECT

This capstone project, *An Examination of Teacher Questioning and Student Responses Within the Context of an Integrated STEM Project*, has been approved by the Graduate Faculty of the Curry School of Education and Human Development in partial fulfillment of the requirements for the degree of Doctor of Education.

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Julia Cohen, Ph.D., Chair

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Jennifer Chiu, Ph.D., Committee Member

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Sarah Fick, Ph.D., Committee Member

________________________________ Date

Abstract

As teachers incorporate more science and engineering practices into their science instruction, it is important for teachers to support students as they engage with these practices. Talking science is one way for students to engage in authentic science practices as part of classroom instruction. However, students are often newcomers to engaging in science talk with teachers or with fellow students. One solution to this unfamiliarity with science talk is for teachers to model science talk and to engage students in classroom discussion through questioning. In this capstone, I addressed a problem of practice aimed at gaining greater understanding of the relationship between teacher talk and student talk. Specifically, I primarily explored teacher questioning, elicited student responses, student-student talk, and groupings of teacher questions and student responses during the enactment of an integrated STEM project. I employed a single-case-study design to examine teacher talk and student talk in two sections of Grade 5 science that were co-taught by the same classroom teacher and STEM specialist at one school. Data collection was archival and included the project's teacher guide and the text transcripts of whole-class discussions during the science-focused lessons. Using deductive and inductive coding and descriptive quantitative analyses, I arrived at research findings about teacher questioning and student talk within the science-focused lessons and about patterns related to groupings of teacher questions and talk moves and elicited student responses. Based on the research findings, I discussed implications for the problem of practice of using questioning to engage students in whole-class discussions and student-student talk and provided recommendations for the context in which this study occurred.

Keywords: teacher questioning, student talk, classroom discussion, science talk

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DEDICATION

I dedicate this capstone to my family as they, in the words of Mr. Feeny,

believe in me when I do not *believe in myself*,

encourage me to *dream*,

tell me that it is ok to *try*,

and always show me how to *do good*.

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CHAPTER 1: INTRODUCTION

As presented in *A Framework for K-12 Science Education*, the vision for science and engineering education for K-12 students is for all students, including students who do not pursue higher education degrees or careers in science, technology, or engineering, to be able "to engage in public discussion on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives" (National Research Council [NRC], 2012, p. 9). Within this framework, the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) articulate a new approach to science learning involving students' authentic use of science and engineering practices (SEPs) integrated with science and engineering disciplinary core ideas (DCIs) and crosscutting concepts (CCCs). The SEPs emphasize discussion-based practices for these students, including constructing explanations, engaging in argumentation through evidence, and evaluating and communicating information (NRC, 2012).

Recognition of the SEPs is necessary to see science as a practice rather than as a collection of facts or as a body of knowledge (NRC, 2012). Understanding science as practice does not discount science as a means of developing theory or of engaging in logical reasoning; rather, understanding science as practice incorporates theory development and logical reasoning into working collaboratively, engaging in scientific talk and writing, developing and testing models and predictions through investigations and data collection, and constructing and defending explanations with evidence (NRC, 2012). These science practices suggest the importance of discussion and collaboration within science. As novices and newcomers, for students to learn the science practices, they need to engage in those same science practices (Lehrer & Schauble, 2006). Students benefit from support and guidance as they engage in these science practices (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Lehrer & Schauble, 2006). Teachers play a key role in guiding (Mascolo, 2009; Mayer, 2004) and scaffolding (Reiser, 2004; Wood, Bruner, & Ross, 1976) their students' engagement in the science practices, especially through classroom talk, discussion, and collaboration. Teachers can model how to engage in classroom scientific discussion to help students participate in authentic science practices (Giamellaro, Blackburn, Honea, & Laplante, 2019; Windschitl, Thompson, Braaten, & Stroupe, 2012). Therefore, one way that teachers guide their students to engage in science practices is through classroom scientific talk and discussion.

For students to engage in science, they need to be able to participate in the communities of practice of science. Students learn the practice by learning the language of that practice (Lemke, 1990). For Lemke (1990), one way for students to engage in the science practices is by learning the language of science. A crucial piece of the NGSS involves students' engaging in scientific talk. I define scientific talk as the means of describing and communicating facts, observations, and explanations through everyday and discipline-specific language and terminology to make sense of the natural world. Constructing scientific knowledge and participating in the science practices to make sense of the natural world are social endeavors (Driver, Newton, & Osborne, 2000; Metz, 2008). Many students are newcomers to science, and they learn to speak and engage like scientists in classroom settings, such as through classroom talk and discussion, with the guidance of teacher scaffolding. Teachers can guide the discussion to support students' participation in the community of practice of science (Herrenkohl et al., 1999; Lehrer & Schauble, 2006). One way that teachers can guide these discussions and engage students in science practices is through questioning (Chin, 2006, 2007; Kang, McCarthy, & Donovan, 2019; van Zee & Minstrell, 1997). There is no one clear definition of questioning (Dillon, 1982). In general, a question is defined as a sentence with an interrogative form or function (Hill, 2016; Newton, 2017). Teacher questioning as part of typical classroom instruction focuses on the questions that teachers ask students, including the types of questions (Dillon, 1982). These questions serve various purposes, such as continuing classroom talk and discussions, guiding student thinking, and promoting participation in classroom discussions (Hill, 2016). Therefore, the purpose of this capstone is to examine the questions that teachers ask and the students' responses to explore students' opportunities to participate in classroom scientific talk.

Background of the Problem

Discussion and science. Learning is social in nature (Dawes, 2004; Lave & Wenger, 1991), and "learning science means learning to talk science" (Lemke, 1990, p. 1). Discussion and language then are related to the process of students' learning science. Scientists work collaboratively and cooperatively with one another as they explore the natural world and develop explanations for natural processes through discussion-based practices (Duschl, 2000), including constructing explanations and engaging in argumentation. Like practicing scientists, students can master a subject like science by learning how to use the language of science (Lemke, 1990), generally through speaking and listening within a science context (Dawes, 2004). For example, when students construct, evaluate, critique, and defend arguments, they engage in discussion to make sense of scientific phenomena using evidence (Berland & Reiser, 2009). Teachers can also use questioning to guide students in classroom discussion as the students engage with the science practices (Chin, 2006, 2007; Kang et al., 2019; van Zee & Minstrell, 1997). These teacher questions support students when the students provide descriptive observations and express their findings to fellow students (Kang et al., 2019). Discussion within the science classroom then can serve various purposes, including a means of learning content but also a means of providing access to scientific practice for students.

Discussion and NGSS. Discussion is an important aspect of NGSS-aligned instruction since each of the SEPs as presented in the NGSS could be connected to discussion when they are implemented authentically in and out of the classroom. The SEPs are language-intensive (NGSS Lead States, 2013, Appendix F) both in terms of formal, discipline-specific science language and vocabulary and in terms of students' engagement with these SEPs through written work and classroom talk (NRC, 2012). Discussion is an essential aspect of these authentic SEPs as defined in and described by the NGSS (e.g., modeling; engaging in argument from evidence and constructing explanations; obtaining, evaluating, and communicating information). As students generate models of concepts and processes, they need to read, write, and often create visual representations of their models (NGSS Lead States, 2013, Appendix D). As students engage in argument from evidence and construct explanations, they speak and listen to one another as they introduce their ideas, defend their ideas from reasoned critiques, and reach conclusions with other students (NGSS Lead States, 2013, Appendix

D). Students' communication with one another can take various forms, including written work, oral presentations, or discussions (NGSS Lead States, 2013, Appendix F), which means that students need to be able to not only produce and present their own information but also consume and assess others' presentations as well. Overall, many if not all of the SEPs as presented in the NGSS are connected to discussion when they are implemented authentically in and out of the classroom (Giamellaro et al., 2019). Therefore, discussion plays an important role for students as they engage in the science practices.

Discussion and access to science. Opportunities to engage in scientific discussion within the classroom can be very beneficial for students, such as increasing student interest in science or feeling a greater sense of belonging in the community of science practice. Within the science classroom, when students have the opportunity to think, speak, and interact with the teacher and with other students through scientific discussion, they are more likely to maintain their interest in science (Watkins & Mazur, 2013). Access to the language of science and scientific discussion is necessary for students to feel a sense of belonging within the science community (Schoerning, Hand, Shelley, & Therrien, 2015). Engaging in scientific discussion provides students with opportunities to participate in the community of science practice.

Formal language of science as a barrier to participation in science. However, the language of science may restrict students' access to participation in scientific discussion because the academic, discipline-specific language of science and the everyday language of students can be so different. With science generally defined in terms of Western science (NGSS Lead States, 2013, Appendix D), enactment of the language-intensive NGSS in the classroom can provide challenges to underserved student groups, including economically disadvantaged students, students from racial and ethnic minority groups, students with disabilities, and students who are English language learners. For these students who do not normally use formal language in science, their access to participation in science is often limited because teachers and other individuals underestimate their understanding of scientific ideas (Blown & Bryce, 2017). These students might understand the science content, but they cannot demonstrate their comprehension because they do not use the formal scientific language (Blown & Bryce, 2017; Brown, 2006). Teachers can address these differences by working to integrate the everyday language of students and the academic language of science within the classroom talk.

Supporting students' science language use with everyday language. Teachers' efforts to use both students' everyday language and the academic language of science to encourage all students to participate in the community of science practice can be beneficial for students. Using everyday language while the students learn the formal, discipline-specific language conventions and vocabulary can allow students to access what they already know about the natural world (Jung & McFadden, 2018). For example, Brown (2011), suggests that science teachers use a framework called "disaggregating instruction." In this framework, the scientific concepts are disaggregated or separated from the science language and vocabulary associated with the concepts. First, the teacher uses students' everyday language to introduce scientific concepts to them, which can reduce the anxiety and frustration that students generally experience when faced with new scientific language. Then, the teacher explicitly introduces the new science language to the students after the scientific concept has already been taught. Finally, the students integrate the new science language and the scientific concept by utilizing the science language to describe and explain scientific phenomena that relate to the new scientific concept through formative assessment activities. Utilizing everyday language provides an avenue for students to learn the more formal, discipline-specific language.

Similarly, Lee and Fradd (1998) and Lee (2004) suggest a framework called "instructional congruence," in which teachers use diverse learners' cultural and linguistic experiences to allow learners to use and apply academic content to their lives. According to instructional congruence, teachers need to explicitly instruct about the norms of classroom science talk, including science language, vocabulary, and classroom science discussions, while also making explicit connections between students' everyday knowledge and the academic content and between the students' cultural and linguistic experiences of their home and community and the cultural and linguistic conventions of modern science. Teachers are expected to gradually move from more explicit, teacher-centered instruction to more student-centered instruction as the students become more accustomed and connected to the culture and practice of science. Through these explicit connections between the students' cultural and linguistic experiences and the academic language and content of science, teachers can scaffold students' introduction to the community of science practice.

Benefits of discussion. Opportunities to practice scientific discussion benefit students. Social interactions and especially classroom discussions are strong drivers of student learning (National Academies of Science, Engineering, and Medicine, 2018). For example, when students participate in classroom discussions in science, their understanding of scientific concepts and their ability to use authentic scientific language improve (Osborne, 2010; Roth, McGinn, Woszczyna, & Boutonné, 1999), their retention in STEM disciplines at the collegiate level may improve (Watkins & Mazur, 2013), and their access and equity to science in the classroom may improve (Windschitl, Thompson, & Braaten, 2018). Further, instructional conversations between teachers and students and among students provide an opportunity for students to develop into a community of learners or a community of practice (Tharp & Gallimore, 1991). These conversations allow teachers to use the classroom community to take students' experiences into account when constructing lessons so that teaching and learning could be interpersonal and collaborative (Tharp & Gallimore, 1991). Instructional conversations can develop into classroom discussions in which teachers are open to listening to what their students say rather than only looking for correct answers. When students have openings to express themselves and to talk science in classroom discussions, they tend to experience greater agency in these discussions and are more likely to lead the discussions (Friend, 2017). Classroom discussions that are open to students' expressing themselves and trying new ideas could develop into stronger classroom communities, and classroom communities provide students with opportunities to practice scientific talk.

Discussion and teachers. Teachers serve an important role in providing students with opportunities to engage in scientific discussion. Discussion, argumentation, and debate are important in the practice of science but are only readily present in authentic classrooms where teachers focus more on science practices than solely on content knowledge (Osborne, 2010). Conversations and discussions between teachers and students can serve to develop students' content understanding (Lemke, 1990) and to develop reasoning and explanations for investigations (Smith & Hackling, 2016). In the classroom setting, teacher-student interactions are important sources of information for students as they learn science (Chin, 2006). Through teacher-student dialogic interactions, teachers allow students the space and opportunity to join the conversation and contribute to the classroom discussion (Zhai & Tan, 2015). These teacher-student interactions can occur in various ways. For example, teachers may begin discussions as the discussion leader, often starting with a question and controlling the flow of the discussion, but over time may take a more passive role in the discussion to give the students an opening to lead the discussions and to approach classroom talk with greater agency (Friend, 2017). In another instance, a teacher used certain language conventions during classroom discussions, such as first-person plural pronouns (e.g., we, our), to identify herself as a member of the community of science and to include her students within the same community (Moje, 1995). Teacher-student interactions then provide students with space and opportunities to participate in classroom discussions. Participating in the classroom discussion provides students an opportunity to participate in the science classroom communities and in turn to begin to participate in the community of science practice.

One way for teachers to guide these classroom discussions is through teacher questioning and other talk moves. Teacher questioning is an important aspect of fostering discussion in science classrooms (Chin, 2006, 2007), and the combination of teachers' questioning and other talk moves can develop and support discussion among students (Smith & Hackling, 2016; Tytler & Aranda, 2015). In traditional lessons, teacher questioning generally is used to evaluate students' content knowledge and comprehension, but in constructivist approaches, teacher questioning is used to determine what students know and to support students' thinking (Chin, 2007). How teachers use these questions determines the type of classroom talk in which the students can engage,

The types of questions that teachers use are also important in fostering science classroom discussion. For example, discussion in the science classroom often takes the form of triadic dialogue (Lemke, 1990), such as initiation-response-evaluation (IRE). The following example of an IRE question sequence illustrates first the teacher's initial question, then the student's response, and finally the teacher's evaluative statement:

> **Speaker A:** What time is it, Denise?
> **Speaker B:** 2:30
> **Speaker A:** Very good, Denise. (Mehan, 1979, p. 285).

These question sequences are often based on closed-ended questions in which the teacher already knows the correct answer and which often end in evaluative statements from the teacher. While evaluation can be purposeful, such as when testing students' content knowledge or when clarifying students' prior knowledge, the evaluative statements generally demonstrate the level of teacher control in the classroom and can limit the amount of student participation in the scientific discussion. Additionally, students cannot engage in authentic SEPs if teachers evaluate their responses and prevent students from testing multiple models or trying to defend or critique various explanations. For example, students cannot engage in authentic modeling if teachers evaluate their models as "correct" or "incorrect." Students also cannot engage in developing explanations authentically if teachers tell them that there is a single correct explanation. However, in contrast to the IRE question sequence, the initiation-response-feedback (IRF) format of teacher questioning can encourage greater student participation in scientific discussion

(Chin, 2006). The following example of an IRF question sequence illustrates the teacher's initial question and the student's response which are followed by the teacher's feedback and a follow-up question to extend the discussion:

> **Teacher:** *What would the shape be?*
> **Student:** Flattened…
> **Teacher:** Okay, *which do you think is the best shape for the maximum exchange of gases?* … You will be judges. Which one would be best? (Chin, 2006, p. 1328, emphasis in original).

In these IRF question sequences, teachers tend to use more open-ended questions and use more feedback and follow-up talk moves than evaluative statements (Chin, 2006). Teachers' use of questioning and talk moves within these teacher-student interactions help to guide and support students as they engage in classroom discussions.

However, teacher-student interactions do not always provide opportunities for students to participate more fully in the classroom discussion. When these teacher-student interactions center too much on teacher talk rather than students' contributions, students' opportunities to participate in classroom discussions become limited (McNeill, Pimentel, & Strauss, 2013). Other times, when teachers try to limit or eliminate their involvement in the classroom discussion, some students may struggle to participate if they lack the appropriate vocabulary used in the discussion or have had different experiences from the students leading the discussion (Kelly & Crawford, 1997). Teachers need to ensure that they balance their own contributions to a classroom discussion by leading rather than dominating the discussion (Chin, 2006; Dawes, 2004) and should enter discussions when necessary to ensure that each student has equitable access to the discussion (Kelly & Crawford, 1997). Teachers' contributions to the classroom discussion can encourage or discourage students' participation in the classroom discussion, which is in turn related to students’ participation in the science community. Teachers, their questioning, and their talk moves then play an important role in the students’ participation in classroom discussion and in the science practices.

Providing opportunities for students to participate in scientific discussion within the classroom community may improve their understanding of science content and may encourage students to more fully identify with the science community of practice. However, research demonstrates that teachers need support to be able to select and employ the appropriate kinds of questions to engage students in scientific discussions. Thus, this capstone focuses on the questions that teachers ask and students’ responses to examine students’ opportunities to participate in classroom scientific talk and to explore developing supports to aid teachers in asking appropriate questions to engage students in scientific discussions.

Theoretical Framework

According to Lave and Wenger (1991) and their view of a theory of social practice, learning is a situated activity that is relational and authentic in nature. Situated learning means that learning is contextualized (Lave & Wenger, 1991). School learning is often decontextualized (Lave, 1991), but school learning can be situated in nature if the learning is grounded in concrete situations (Brown, Collins, & Duguid, 1989) like authentic practice. Learning and social practice continuously generate each other, and this process of engaging in social practice where one goal is learning is described as legitimate peripheral participation (LPP). In the LPP of a community of practice, peripherality is related to relevant or authentic activity of the community of practice. Peripheral participation does not need to embody the full range of activities of the community of practice, but it needs to relate in some way to the community of practice and potentially serve as an opening for a newcomer to become a full participant in the community of practice.

Learning suggests that a person is a social part of the world and a member of a community (Lave & Wenger, 1991). Through LPP, the newcomer to the community of practice learns to talk like the other practitioners (Lave & Wenger, 1991). In this sense, through learning, a person develops a new identity through the connections made between the person and the outside world and especially between the person and the community. For example, Lemke (1990) wrote, learning to do science is the same as learning to talk science, and talking science means using the language of science to engage collaboratively and in discussion with other members of the community of science practice. In the context of this capstone, learning to talk science in the context of the classroom discussion may help students begin to participate as newcomers in the community of science practice.

In later iterations of the theory of community of practice, Wenger (1998) moves away from legitimate peripheral participation, which is a description of how the newcomer enters the community of practice and works to become a full participant. Instead, community of practice focuses on mutual engagement, or the interaction between individuals that creates common significance with an issue or problem; joint enterprise, or the way that individuals work together to reach a shared objective; and shared repertoire, or the common tools and vocabulary that group members use within the group (Wenger, 1998). In the most recent iteration, communities of practice are collections of individuals (i.e., the community) who share an interest (i.e., the domain) for some practice (i.e., the practice) that they engage in and who learn the practice better as they interact (Wenger-Trayner & Wenger-Trayner, 2015). The practice of the community constantly changes, and every member, whether a newcomer or a full participant, learns as part of the community (Wenger-Trayner & Wenger-Trayner, 2015). However, as part of education, when considering school learning through the lens of a community of practice, there are three aspects that must be considered. First, the educational experience should be grounded in authentic practice around the content. Second, the educational experience should be connected to the actual practice of communities outside the school, and efforts should be made to connect the students to these communities. Third, the educational experience for the students should last after leaving the class or the school, and efforts should be made to connect the students to topics that continue to interest them (Wenger-Trayner & Wenger-Trayner, 2015). Therefore, the community of practice should be relevant to the participants (i.e., the students), and the members should engage in practices that are situated in authenticity.

Access is a core issue in situated learning and in LPP within a community of practice (Lave & Wenger, 1991). Students need to access the practice in order to learn (Lehrer & Schauble, 2006). Without access to legitimate, peripheral activities, newcomers to the community of practice will never become full participants (Lave & Wenger, 1991). Giving students the access to opportunities to act as scientists gives them opportunities to learn the practices of science. However, as newcomers to the community of science practice, students might not know how to engage in the science practices and in classroom discussions with one another. Teachers can model how to engage in classroom scientific discussion (Windschitl et al., 2012) and scaffold student participation in these classroom discussions (Herrenkohl et al., 1999) through questioning (Kang et al., 2019; Merritt, Chiu, Peters-Burton, & Bell, 2018). The questions that the teachers ask to guide the students in classroom discussions can also serve as a gateway or barrier to access to the community of practice. Since scientists address all types of questions, teacher can model science practices by asking a range of questions, including open- and closed-ended questions. However, the open-ended questions encourage the students to develop their reasoning skills more fully and to think more like scientists. Through these modeling and scaffolding questions, teachers provide students with opportunities to participate in the science practices, such as classroom discussions, to act as scientists, and to access the community of science practice, even as newcomer scientists.

In the context of this capstone, students, as newcomers, might not be able to participate as full members in the community of science practice, but they can have access to opportunities to act like newcomer scientists. Talking like scientists in classroom discussions, such as with the support of teachers' guided questioning, is a form of LPP as it provides students with opportunities to talk like full participants in the community of practice. Through their questioning and talk moves, teachers serve an important role in modeling science practices and providing students with opportunities to participate as newcomers in the community of science practice.

Problem of Practice

The site for this capstone project was a small, suburban school district in the southeastern United States, Spring City Public Schools (SCPS; pseudonym). This district has large populations of students who come from backgrounds of low socioeconomic status and from backgrounds of racial/ethnic minorities who are underrepresented in

STEM (e.g., Black, Hispanic). This project focused on examining the classroom discussions within these classrooms that represent this diversity.

Within this district, there has been a push to integrate STEM content areas at all grade levels and to provide all students with the opportunity to join engineering classes. Within this integrated-STEM (or iSTEM) program, there is a large emphasis on access for all students to the STEM content areas in general and to engineering in particular (School District, n.d.). The iSTEM program also emphasizes project-based, hands-on instruction for all students. The iSTEM program works in all of the district's schools and at every K-12 level to demonstrate foundational STEM concepts to the students and teachers; help teachers make connections among science, technology, mathematics, and engineering while also making connections to art, history, and reading; and develop students' understanding in engineering and to encourage students' participation in the engineering programs offered at the district's secondary schools.

This capstone focused on one integrated STEM project called Science Projects Integrating Computing and Engineering, or SPICE. The SPICE project focuses on developing elementary and middle school curricula that use computational thinking activities to connect science and engineering. The SPICE curriculum aims to integrate computational thinking, scientific reasoning, and engineering design through computational modeling in an earth science unit (Chiu et al., 2019). Computational thinking is a way to represent variables and to express the quantitative relationships among these variables, such as through simulations (NRC, 2012). Scientific reasoning encompasses a wide range of practices employed by scientists, including deductive reasoning, searching for patterns, methods of classification, generalizing from multiple observations, and inferring best explanations (NRC, 2012). Engineering design can be characterized as defining a problem, identifying constraints for developing solutions to the problem, creating and assessing solutions to the problem, and testing and adjusting these potential solutions (NRC, 2012).

The problem of practice for this capstone study involved supporting teachers to implement NGSS-aligned instruction that integrates the fields of engineering, computation, and science. This district is interested in increasing students' access to the STEM content areas and in encouraging student engagement in science talk and other science practices and student participation in the science community. In addition, the teachers and administrators in this district are interested in how teachers use questioning to support students' engagement in the SEPs through discussion and creating explanations and their engagement in discussion with their fellow students. Therefore, my capstone focused on teachers' use of questions and the relationship between teacher questioning and student participation in classroom discussion within science-focused lessons during the enactment of the SPICE curriculum.

Even when teachers encourage scientific discussion in the classroom, classroom discussion often flows through the teacher (Cazden & Beck, 2003), suggesting that the teacher wields the power in these situations. What students say in class is important because what they say helps teachers and researchers to understand how they are engaging with the science practices. If what the students say flows through the teacher and is prompted by teachers' questions, then we should examine the teachers' questions and the students' responses to understand how the teachers encourage students' engagement in science and the science practices. How can we help teachers position themselves as outside the central focus of the discussion while they guide student participation in the discussion through questioning and other talk moves? This question drives the purpose of this capstone study.

Purpose of the Current Study

This capstone explored teacher questioning and subsequent student responses as teachers implemented an NGSS-aligned project that connects science, engineering, and computational modeling. Specifically, as the focus teachers implemented an NGSS-aligned unit, the capstone examined teachers' questioning and opportunities for student responses within science-focused lesson and across the lessons within the unit. Additionally, the capstone also examined the relationship between the type of question and the corresponding type of student response and the patterns across the teacher question, student response, and teacher talk move.

The following research question guided this study:

(1) What kinds of teacher questioning and opportunities for student response are present in the discussions during the enactment of the SPICE curriculum?

    a. In whole-class discussions, what is the frequency of teacher questioning as compared to student response?

    b. In whole-class discussions, to what extent do frequency and kind of teacher questioning and student response differ by lesson?

    c. In whole-class discussions, what kinds of questions do teachers ask, and what kinds of student responses do these questions elicit?

Definition of Terms

This section includes a list of terms and their definitions. These terms will be used throughout this capstone project.

Discourse: According to Gee (1989), discourse (lowercase) represents "connected stretches of language that make sense" (p. 6). Discourse includes but is not limited to oral and written communication. According to Lave and Wenger (1991), discourse is an active form of communicating and learning. For the purposes of this study, discourse will primarily refer to talk or more specifically oral communication between teachers and students and among students.

Discussion: In the classroom, discussion refers to oral communication between teachers and students or among students. A discussion generally has a back-and-forth exchange between students and teachers or between students and students. A discussion is generally but not necessarily initiated by a question.

Scientific talk: Scientific talk (or science talk) refers to the talk used to describe and communicate facts, observations, and explanations through everyday and discipline-specific language and terminology to make sense of the natural world.

Classroom talk: Classroom talk refers to speech by the student (i.e., student talk) or by the teacher (i.e., teacher talk). It can be associated with various types of speech, including teacher-student discussion or a student-student discussion with a back-and-forth exchange, a teacher question that may or may not receive a response, or a comment made by a student or a teacher. For the purposes of this research study, classroom talk generally refers to classroom discussion.

Questioning: In the classroom, questioning is often initiated by the teacher. Teacher questioning involves the teacher or teachers asking one or more students a question about the content. The purpose of the question could be varied (e.g., to evaluate students, to elicit students' thinking, to ask students to elaborate their thinking, to set up a procedure or activity, to serve a rhetorical purpose, etc.). There are multiple question categories (e.g., open, closed, higher-order, lower-order, etc.).

Situated activity: According to Lave and Wenger (1991), all activity is situated. Situated activity involves the whole person and how the person acts and interacts in and with the world. All activity is situated in that learning is relational in nature and that the learning activity is authentic or legitimate (i.e., "dilemma-driven" [p. 35] or problem-based). Situated activity focuses on the person as an actor in the world and as a member of a community.

Legitimate peripheral participation (LPP): According to Lave and Wenger (1991), LPP is the process that defines learning as a situated activity. Learning is a part of social practice in the world, in which social practice generates learning and learning in turn generates social practice. LPP describes the process of engaging in social practice that has learning as one of its goals. Peripherality means that various ways of participating in a community exist, with varied levels of engagement and inclusivity. Peripherality is also related to relevant or authentic activity. Peripheral participation does not need to embody the full range of activities of the community of practice, but peripheral participation needs to relate in some way to the community of practice so that this participation can serve as a potential path for a newcomer to eventually become a full participant.

Community of practice: According to Lave and Wenger (1991), a community of practice is comprised of practitioners who begin as newcomers and who become old-timers or experts over time. The participant's knowledge, skills, and discourse change within the community of practice as the participant develops an identity within the community of practice. Communities of practice exist in a social world and so are involved in the transformation and change of their members in part for continuous reproduction of the community of practice. The members of a community of practice are expected to have a common understanding about the nature, goal, and meaning of the practice. Learning is decentered within the community of practice so that the focus of learning should be on the community of practice rather than on an individual learner.

Chapter Summary

In this first chapter, I provided background on talk within a science classroom. Then, I demonstrated how the language of science can be a barrier to students' participation in science talk and scientific discussion. Next, I introduced the idea that teachers can serve a role in providing students with access to the community of science practice. Teachers can serve this role by way of teacher questioning and other talk moves, which in turn can provide students with opportunities to talk as newcomers in the community of science practice. I situated this research study within the specific problem of practice related to students' access to participation in the community of science practice and described the purpose of the capstone and the research goal of exploring the relationship between teacher questioning and student responses within an integrated STEM curriculum. I also described legitimate peripheral participation, situated learning, and communities of practice, which served as the theoretical framework that I used to guide my thinking throughout the capstone process. Finally, I listed and defined relevant terms that were used throughout this chapter and the remainder of the capstone. In the next chapter, I provide information about literature that is relevant to this research study.

CHAPTER 2: LITERATURE REVIEW

When teachers provide opportunities for students to participate in scientific talk and discussion within the classroom, they are supporting students to begin to participate legitimately in the community of science practice. This literature review focuses on teachers' roles in providing opportunities, primarily through questioning and talk moves, for students to participate in science talk. First, I describe how scientific talk is part of the practice of science. Second, I describe how classroom discussion supports science learning, primarily through teacher talk and student talk within classroom discussion. Third, I describe discussion within the context of teacher-centered and student-centered instruction to demonstrate how questioning and other talk moves either limit student talk or provide students with the space and opportunity to talk. Finally, I describe the use of teacher questioning and talk moves as strategies for teachers to provide opportunities to students to participate in scientific talk within classroom discussion. These opportunities to participate in classroom talk provide students with the opportunity to act as newcomers in the community of science practice.

Engaging in the Practice of Science

While science has been viewed in various ways over time, including as a form of logical reasoning (Chen & Klahr, 1999), as the development and change in theories (Kuhn, 1962), or as a large body or collection of accumulated scientific knowledge (Livingstone, 2003), recognizing the importance of science as practice (Pickering, 1995) is essential to understanding science as more than a collection of facts (NRC, 2012). Science practitioners engage in these practices to achieve the goals of science as understanding and making sense of the natural world (Metz, 2008). The *Framework* (NRC, 2012) identifies eight science and engineering practices (SEPs) so that students can build knowledge and make sense of the natural world by engaging in doing science: (1) asking questions and defining problems; (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 and designing solutions; (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information.

These science practices are collaborative in nature (NRC, 2012). Science practitioners collaborate when individuals, groups, and institutions directly work together to develop models as representations of systems or phenomena or develop and test predictions and hypotheses through planning investigations and collecting data. These science practices also represent collaboration when science practitioners communicate with each other through particular speaking and writing patterns that are specialized to science, such as through writing in the passive voice or through distinguishing between formal and colloquial definitions of terms like “energy.” Further, science practitioners work together to construct explanations and to critique and defend these explanations using evidence, such as through an informal or formal discussion or a more formal peer review process. This wide range of science practices helps to highlight the importance of language, discussion, and collaboration within the realm of science.

Science practices and connections to scientific talk and discussion. The practices of science describe how science is done, and science is undertaken to develop scientific knowledge and to make sense of the natural world. Developing scientific knowledge and participating in science practice are social (Driver et al., 2000; Metz, 2008) in nature. Classroom discussion is a social practice because it is based on the action and interaction of oral language (Gee, 2004) conducted by teachers and students (Sawyer, 2004). As Driver, Newton, and Osborne (2000) argue, greater attention should be paid to science practices like discussion that are social since scientific knowledge is socially constructed. Through discussions, science can be practiced socially, such as through the collaboration of multiple scientists to conduct an investigation that could not be completed by a single investigator (Metz, 2008) or through the analysis, evaluation, and critique of an explanation of a particular scientific phenomenon (Driver et al., 2000). In either case, scientists engage in discussion with one another, whether through written or oral communication. As a social practice, these discussions are a form of communicating and learning (Lave & Wenger, 1991) for science practitioners.

Within the school setting, discussion can also serve as an introduction to the social nature of science practices. Science curricula should be designed for students to learn about science but also to provide opportunities for students to do science (Metz, 2008). As described above, the *Framework* identifies eight SEPs with which students can engage to construct scientific knowledge. These SEPs are language-intensive, and participation in these SEPs means that students must engage in classroom talk, especially classroom discussion (Lee, Miller, & Januszyk, 2014; NGSS Lead States, 2013, Appendix F). In particular, the science practices of developing and using models to demonstrate data and concepts; engaging in argumentation and constructing explanations to critique one's own and others' ideas; and obtaining, evaluating, and communicating information are essential parts of building knowledge through scientific talk and discussion (Duschl & Grandy, 2013; Osborne, 2010). These science practices and their relationship to discussion are described in further detail below.

Developing and using models. Models can be used to demonstrate data and concepts. Models can range from concrete pictures or scale models to more abstract conceptual representations (NRC, 2012) and can include "diagrams, physical replicas, mathematical representations, analogies, and computer simulations" (NGSS Lead States, 2013, Appendix F, p. 52). In addition, models can help to develop questions and explanations and to communicate ideas and concepts to other science practitioners as well as to the general public (NRC, 2012) because scientific models are tools for predicting and explaining natural phenomena (Schwarz et al., 2009). Models also change or are revised as new evidence about a phenomenon arises and as understanding of the natural world improves (Schwarz et al., 2009). While models may serve as representations of concepts, ranging from ways to illustrate to ways to explain these concepts (Schwarz et al., 2009), they also serve as valuable aids in communicating these concepts to others.

In response to the prevalence of the scientific method, Windschitl, Thompson, and Braaten (2008) offer model-based inquiry, which served as a different view of science and its purpose of investigating and exploring the natural world. Like Schwarz et al.'s (2009) understanding of modeling, model-based inquiry emphasizes that models can be tested and revised when new evidence arises, are used to explain and predict phenomena, and can serve as the basis for new predictions and hypotheses about phenomena

(Windschitl, Thompson, & Braaten, 2008). Windschitl et al. (2008) suggest that teachers can present model-based inquiry to their students through a set of four conversations or discussions.

Each of these discussions focuses on a different aspect of modeling, and the researchers present questions that teachers can use to support students as they engage in these discussions about modeling. The first discussion, supported by questions like "What questions does this model help us ask?" (Windschitl et al., 2008, p. 17), helps to determine what phenomenon of the natural world interests the students and also emphasizes that the chosen phenomenon must suggest processes or properties that can be explained through the model. The second discussion, supported by questions like "What aspects of our models do we want to test?" (Windschitl et al., 2008, p. 18), focuses the conversation on how the model and predictions associated with the model are testable.

The third discussion, supported by questions like "What kind of data would help us test our hypotheses?" (Windschitl et al., 2008, p. 18), focuses on collecting data and other evidence to test the model and recognize patterns or associations within the natural world. The fourth discussion, supported by questions like "Was what our original model predicted consistent with the data we collected?" and "Should our model change in light of the evidence?" (Windschitl et al., 2008, p. 19), focuses on exploring the data for patterns and using that evidence to support, revise, or refute the proposed model. Teachers use these questions to support and guide students through these model-based inquiry discussions and through the process of developing models. These models may be descriptive, illustrative, or explanatory in nature, but developing and using models is an important science practice to construct explanations and communicate ideas and understandings to others. Teachers serve an important role in guiding students as they develop, revise, justify, and disseminate these models.

Argumentation and constructing explanations. Constructing explanations and engaging in argumentation from evidence are also essential forms of scientific talk and discussion. According to Duschl, Ellenbogen, and Erduran, (1999), the language of science is the kind of talk that uses data and evidence to construct, justify, and critique explanations. Students need to be able to engage in argumentation by constructing and critiquing their own ideas and other students' ideas through discussion (McNeill, 2015). Through these critical discussions, students can participate in argumentation as a communal practice (Manz, 2015)

For students to participate in argumentation as a communal practice, argumentation should be taught in the classroom. Teaching argumentation in the classroom can serve two purposes: first, it can show students that science is constructed socially, especially with science as a discussion-oriented practice; and second, it can provide students with opportunities to create, analyze, and evaluate arguments or scientific claims, especially when the social implications of the science are large (Driver et al., 2000). When students create, analyze, and evaluate arguments, they engage in scientific discussion, whether through speaking or writing, to use evidence to make sense of scientific phenomena and to articulate their understandings of these phenomena (Berland & Reiser, 2009). However, when students struggle with developing arguments and constructing explanations, teachers can support students in these practices.

One way for teachers to support students' understanding of argumentation and explanations is through making the rationale for scientific explanation explicit (McNeill

& Krajcik, 2008). In one study of a project-based chemistry unit in thirteen seventh-grade classrooms, when teachers made the rationale for scientific explanations explicit, students began to understand why evidence and reasoning were needed to support and justify their claims. Teachers can also model how to create scientific explanations (McNeill & Krajcik, 2008), which can help to demonstrate to students and serve as a guide for students in how to construct explanations. In a smaller study of three high school teachers in urban ecology courses, one teacher's classroom exhibited student-student discussion and students explicitly supporting and refuting one another's claims (McNeill & Pimentel, 2010). In contrast to the other teachers in the study, this teacher supported students' contributions to the classroom discussion through open-ended questions and making clear connections and references to students' comments and ideas (McNeill & Pimentel, 2010). The open-ended questions guided students as they constructed explanations and justified their claims with discipline-specific and everyday knowledge, and the clear references to students' ideas supported students as they thought about their own and their classmates' thinking (McNeill & Pimentel, 2010). Teachers can use these open-ended questions and the references to student talk within the discussion to encourage student participation in classroom discussions and to support students in constructing explanations. Argumentation is a key science practice in which students can participate communally, and teachers serve an important role in guiding students' participation in discussion and supporting students' use of evidence in justifying explanations.

Obtaining, evaluating, and communicating information. Obtaining, evaluating, and communicating information is an essential practice of science talk and discussion. As described in the *Framework* (NRC, 2012), communicating through writing or speaking "requires scientists to describe observations precisely, clarify their thinking, and justify their arguments" (p. 74). In other words, this science practice connects to the discussion-related nature of the other SEPs as described in the NGSS. In order to develop their communication abilities, students should have the opportunity to engage in discussions about observations and explanations, oral presentations about results and conclusions, and critiques of other students' claims (NRC, 2012). However, the language of science differs from students' everyday language (Buxton, 2005; Lemke, 1990; NRC, 2012), so teachers can help to develop students' understanding of scientific language and their ability to communicate information in the classroom.

One way that teachers can model communicating information and guide students to communicate their findings to others is through questioning (Kang et al., 2019; Merritt et al., 2018). Teachers use these questions to facilitate eliciting responses from students, encouraging students to provide more description in their observations, and guiding students' thinking. Communicating information is an essential science practice, but teachers serve an important role in developing students' proficiency with the language of science and communicating information through written and spoken modes.

Scientific discussion and access. Engaging in scientific talk provides students with opportunities to participate in the community of science practice. In order to participate and to feel a sense of belonging within the community of practice, students need access to the language of science (Schoerning et al., 2015). While I define scientific talk as a way to make sense of the natural world through everyday and discipline-specific language and terminology, the language of science can also be understood as the formal and discipline-specific language conventions and terminology that practicing scientists use in formal settings, such as conferences and publications. However, the formal, discipline-specific language of science may restrict students' access to participation in scientific discourse. Students may find learning the formal language, expressions, and vocabulary of certain disciplines, such as science and engineering, difficult to learn, but using everyday language within the classroom while the students also learn the discipline-specific language conventions and vocabulary can allow students to access what they already know about the natural world and provide students with opportunities to participate in classroom talk (Blown & Bryce, 2017; Jung & McFadden, 2018).

Within the field of science, scientific talk and discussion incorporate a certain linguistic style that is not familiar to new science learners (Buxton, 2005; Lemke, 1990). The linguistic conventions of science and engineering include the use of passive voice in writing, the use of discipline-specific and content-specific vocabulary, and the use of data and evidence in making claims (NRC, 2012; Osborne, 2010). Using common language conventions for science and engineering is important in formal situations, such as during conferences, when presenting research, in journals when writing about research, and in communication between scientists (NRC, 2012). A common language structure allows for more straightforward communication between scientists, but this language of science is different from everyday language conventions (NRC, 2012) and is unfamiliar to many students (Buxton, 2005), thereby serving as a barrier for some students to engage in scientific discourse and science discussions in the classroom (Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). While the language of science may be unfamiliar to many students, teachers can utilize students' everyday language in conjunction with the language of science to bring students into the community of science practice.

Formal, discipline-specific scientific language can make science difficult to learn for some students, thereby limiting the access of these students to the community of science practice. According to Scott (1998) in a review of the literature, learning to talk science is more complicated than only learning to say the words and phrases of a new content area. Instead, science is a field of study and practice that involves ways of thinking, reasoning, and communicating that are different from everyday practices. Science as practiced in the classroom should reflect how science is practiced in other authentic contexts outside the classroom (Stroupe, 2014), and teachers can act as guides for the students to the culture and practice of science (Scott, 1998) in their classrooms, especially through classroom discussion.

How Students Learn Science

According to the research report *Taking Science to School*, students should be encouraged to connect with meaningful problems in the science classroom and to experience science as practice (Duschl, Schweingruber, & Shouse, 2007). Many science practices are strongly connected to social interaction, including talking through problems with peers in formal or informal settings, constructing arguments and explanations using evidence, exchanging feedback, and evaluating ideas (Duschl et al., 2007). Like these practicing scientists, students can also engage in a community of science practice through social interactions by talking and writing about problems in science, asking questions, generating models, constructing arguments and explanations, and communicating information (Duschl et al., 2007). These social interactions are beneficial for students.

For example, while participating in hands-on investigations, students' learning improves when they communicate their ideas, arguments, and evidence about the investigations to their fellow classmates (Crawford, Krajcik, & Marx, 1999). By engaging in these classroom discussions, students learn scientific concepts and begin to participate in the community of science practice, but they require guidance and support to develop their expertise in the science practices, including articulating ideas, making sense of data, and discussing and reflecting on the data and results.

Learning through classroom discussion is in line with sociocultural (Mercer & Howe, 2012) and situated approaches to learning (Green & Dixon, 2008). In sociocultural theory, an individual's external world and internal mind both influence learning, with the focus on how an individual interprets the external world, including social interactions, through language and speech which in turn affect internal thought (Vygotsky, 1978). Within sociocultural theory, social interactions are crucial because knowledge is constructed through the interaction between two or more people which allows for the generation of a community of understanding (Cobb, 1994). Teachers can organize classroom discussions to serve as times when students construct content understanding through classroom talk. In situated learning approaches, individuals construct their knowledge and their learning through participation in authentic activity (Brown et al., 1989; Lave & Wenger, 1991). By participating in authentic activity, the individual acts like the practitioner, allowing the individual to become a part of the practitioner's culture (Brown et al., 1989) or a fuller member of the practitioner's community of practice (Lave & Wenger, 1991). Participating in classroom discussions provides students with opportunities to engage in learning through social interaction and to participate more fully in the practices of science.

Classroom Discussion

One means of supporting student learning is through engaging in social interaction. Talk is important for students to learn (Alexander, 2006) since talk serves to mediate the space between the teacher and the student, between the student and fellow students, and between what the student already knows and what the student does not yet know (Alexander, 2008). Within classroom contexts, classroom talk might look like engaging in whole-group class discussion or engaging in small-group talk with the teacher and other students. Students make sense of activities and problems by engaging in classroom talk and discussion with the teacher and other students (Dawes, 2004). In traditional classroom lessons and discussions, the instruction tends to center on the teacher (Cazden, 2001). This teacher-centered instruction often utilizes recitation, which focuses on factual recall and students' content comprehension during a lesson (Nystrand, 2006). However, educational reforms generally call for instruction that is more centered on the student, especially through inquiry instruction and increased discussion (Cazden, 2001; NGSS Lead States, 2013). While traditional lessons flow primarily through the teacher, reform-based lessons consider the classroom as a community of learners rather than as a collection of individual students (Duschl et al., 2007). Research has indicated that student-centered instruction allows for greater opportunity for student voice to enter classroom discussion (Martin & Hand, 2009) and is associated with greater student achievement (Odom & Bell, 2015). To support students' access to the classroom discussion and in turn to the community of science practice, teachers guide student participation in the classroom discussion (Herrenkohl et al., 1999; Lehrer & Schauble, 2006) through questioning (Chin, 2006, 2007; Kang et al., 2019; van Zee & Minstrell, 1997). However, teachers struggle to incorporate the reform-based teaching and student-centered instruction in their classrooms (Capps & Crawford, 2013; Gillies & Nichols, 2015; Weiss, Pasley, Smith, Banilower, & Heck, 2003), so they may benefit from guidance on the types of questions that limit student access to the classroom by centering the discussion more on the teacher and that encourage student talk by centering the discussion more on student participation.

Teacher-centered instruction. Teacher-centered instruction tends to flow through the teacher. In teacher-centered instruction, the teacher does not add to students' contributions to the classroom discussion by building on students' ideas or bringing students' lived experiences into the discussion (Thompson et al., 2016). Instead, the teacher exhibits control over the lesson and serves as the primary voice in the classroom both in terms of talk and in terms of making sense of the disciplinary content (Bleicher, Tobin, & McRobbie, 2003; Mercer, 2010). In this type of instruction, the teacher tends to be the primary speaker. When the teacher brings the students into the classroom talk, the teacher tends to use closed-ended questions to evaluate students' comprehension of the material (Mercer, 2010). These closed-ended questions usually invite brief responses which the teacher can quickly evaluate as correct or incorrect. By focusing on whether a student's idea is right or wrong, teachers miss the opportunity to engage with the substance of the student's idea (Cazden, 2001). These brief exchanges fall short of the type of classroom discussion that can resemble the science talk of practicing scientists.

Although classroom talk is important for the development of students' content understanding and epistemic understanding of science, student talk is often limited in the science classroom. In his research, Lemke (1990) describes most of the interactions in the classroom as teacher-driven or teacher-centered. If the focus of the classroom discussion is on the teacher rather than on the student, students' opportunities to interact with each other and with each other's ideas are limited. Further, if the science classroom discussion is driven by the teacher, then the students may focus on the correct answer or on the correct way of doing things rather than on appropriate reasoning (Berland & Reiser, 2011). The classroom talk aligns with the goals of the instruction: when the instructional goal is to find the right answer, then the classroom talk focuses on finding the right answer, whereas when the instructional goal is to participate in discussion, then the classroom talk focuses on discussion and on supporting one's ideas and reasoning within that discussion.

Characteristics of teacher-centered classroom talk. In one study in an Australian secondary school, Bleicher et al. (2003) describe the teacher-centered classroom discussion that occurs in one eleventh-grade chemistry classroom during a unit on electrochemistry. One group of researchers has proposed a set of three characteristics of teacher-centered instruction (Bleicher et al., 2003). (1) The teacher focuses on understanding terminology rather than explaining relevant scientific concepts. In their example, many of the teacher's questions center on testing students' comprehension of relevant vocabulary. (2) Teacher-centered classroom discussion provides few opportunities for students to talk science and to think about scientific concepts so that the teacher can cover all the course content with the students. The teacher controls the classroom discussion through three main strategies: (a) repeating students' responses to re-assert his control of the classroom discussion; (b) stressing key words while asking questions; and (c) interrupting students, especially when the students answer a question incorrectly or make an incorrect conclusion. (3) The teacher's questioning strategies, primarily selecting students to answer questions rather than waiting for students to voluntarily respond, prevent students from engaging in opportunities to talk science and to think about scientific concepts during the classroom discussions. The teacher tends to control the classroom discussion by selecting which students respond rather than leaving these students to volunteer their responses. Based on discussion with the teacher, Bleicher et al. (2003) conclude that the teacher controls the classroom talk in order to finish the designated lesson plan for that class period.

This teacher-centered instruction and the corresponding predominance of direct, closed-ended questions with factual recall and recognition responses (Cicchelli, 1983; Hancock, Bray, & Nason, 2002) highlight the focus on the correctness of students' ideas and limit students from engaging in talking science and from constructing their understanding about scientific concepts. In addition to the above characteristics, (4) this type of instruction is also generally linear, with the teacher presenting the content in the one and only way that it could be understood. The teacher constructs the understanding for the students, and the students listen passively or participate only when the teacher invites them. When the instruction centers on the teacher and the questions center on correct or incorrect responses, the students miss opportunities to participate in science talk and to construct their own understandings of the scientific content.

Teacher-centered classroom talk and science. While participating in classroom discussion can provide students with opportunities to engage in the social nature of science practices, discussion in the science classroom is generally not as authentic as the type of science discussion and science talk in the community of science practice. As opposed to “true dialogue” (Lemke, 1990) or true argumentative discussion in which students critique one another and defend their claims through evidence and reasoning, the classroom discussion flows through the teacher, with the teacher directing the students to demonstrate their reasoning and to explain their understanding. Classroom science teachers often ask students to focus their science practices on predicting outcomes, observing investigations, analyzing and summarizing data, and presenting their conclusions (Lee & Fradd, 1998).

However, if students do not know how to approach scientific thinking through reasoning and critique as opposed to algorithmic procedure and correct answers, the classroom teacher should serve as a guide for the students to look at science talk as a means for being able to reason rather than being right. Teacher-dominated classroom talk can cause problems with the science talk in the classroom, but teacher-guided discussion can instead focus on student thinking (Chin, 2006; Fung & Lui, 2016). If teachers center the classroom science discussion on the student, such as through effective questioning, they can position the classroom science discussion in a way that enables students to participate in classroom talk that focuses on thinking and reasoning (Chin, 2006) rather than classroom talk that only focuses on correct answers.

Student-centered instruction. In contrast to teacher-centered instruction which centers the teacher in a position of control and knowledge construction, through student-centered instruction, the teacher invites the students to participate in the classroom talk in such a way that provides them with greater voice and greater authority in the classroom discussion and that provides a space for them to construct knowledge with one another (Cicchelli, 1983; Hancock et al., 2002). Student talk in the classroom is necessary for student-centered instruction (Windschitl et al., 2012) because student talk engages students to reflect on and express their ideas and any aspect of the talk that they do or do not understand (Michaels, O'Connor, & Resnick, 2008). Through this greater degree of participation in the classroom talk, students begin to participate more fully in the community of science practice by talking science.

Characteristics of student-centered classroom talk. Student-centered instruction, also called reform-oriented instruction, generally incorporates discussion or classroom talk into classroom instruction (Cazden, 2001). While classroom talk is present in teacher-centered instruction, the teacher controls the classroom talk in a teacher-centered classroom. Teachers ask convergent questions, or questions with a correct or incorrect answer, and the students' responses do not have an influence on the direction of the lesson (Cicchelli, 1983; Dawson et al., 2002). In contrast, student-centered instruction provides opportunities for the teacher to ask divergent questions, or questions without one correct answer (Cicchelli, 1983; Dawson et al., 2002), and to be responsive to students' ideas and questions, such as through using students' ideas to move the lesson forward, paying attention to students' participation in the classroom community, and incorporating students' lived experiences into the lesson (Thompson et al., 2016). Additionally, the students' voices influence the focus and the direction of a lesson (Martin & Hand, 2009) in student-centered instruction. When the teacher does not lead the classroom discussion but instead is in the middle of the classroom discussion or lets the students run the discussion, students' sense of agency within the classroom environment tends to increase (Friend, 2017; Goodman, Hoagland, Pierre-Toussaint, Rodriguez, & Sanabria, 2011).

Student-centered instruction and space for student participation. Students are given agency in the classroom when a teacher is responsive to students' thinking, thereby giving the students opportunities to shape the discussion. Across multiple content areas, a teacher's responsiveness to students' ideas and encouragement of student participation in classroom discussion, such as through prompting students to add to their responses or explain their reasoning in greater detail, are related to greater instances of student participation in classroom discussion (Chinn, Anderson, & Waggoner, 2001; Scott, Mortimer, & Aguiar, 2006). Additionally, when a teacher is more responsive to students' voice in the classroom discussion, students tend to demonstrate greater learning gains than when a teacher is not responsive to students (Chinn et al., 2001; Murphy, 2007; Rojas-Drummond & Mercer, 2004; van Zee & Minstrell, 1997). For example, in a comparison of Mexican teachers of mathematics and literacy, Rojas-Drummond and Mercer (2004) demonstrate that students achieve greater learning outcomes with teachers who employ open-ended questions that guide students' understanding and that move beyond testing comprehension (i.e., student-centered instruction) compared to teachers who employ more traditional, closed-ended questions that only test comprehension of factual knowledge (i.e., teacher-centered instruction). Further, in a meta-analysis that examines programs for teaching science, Murphy (2007) describes that the most positive learning outcomes are associated with the combination of hands-on activity and relevant classroom discussion. Therefore, student-centered instruction is related with greater student achievement, greater student participation in classroom discussion, and greater student agency in the focus and direction of the lesson.

Teacher guidance in classroom talk. While student-centered instruction is related to greater student participation in classroom discussion and greater student participation is related to greater participation in the community of science practice, collaboration among students is not guaranteed to be useful in developing understanding of science practices or deeper reflection of scientific ideas. According to Mercer (1996) and Mercer, Dawes, Wegerif, and Sams (2004), research does not suggest that students who work together necessarily know how to engage in discussion to construct their scientific knowledge effectively. Instead, teacher guidance and scaffolding play an important role in helping students to participate in productive classroom discussion (Chin & Osborne, 2010; Hogan, Nastasi, & Pressley, 1999; McNeill, 2011; Mercer, Dawes, Wegerif, & Sams, 2004; Monteira & Jiménez-Aleixandre, 2016). In classroom discussions, teachers can serve in a guiding role, in which they do not provide information directly but encourage students to add to their reasoning and provide clearer explanations (Hogan et al., 1999). Teacher questions can serve to guide and scaffold students' participation in classroom discussion. For example, the following exchange among the teacher and the students demonstrates how the teacher guides the discussion by encouraging the students to create and refine their ideas about the shapes of atoms and molecules and the shapes of the substances that atoms and molecules make up:

> **Teacher:** Okay, now what would a liquid look like if you could magnify it millions of times?
> **Student 1:** Probably the same thing.

Student 3: Yeah, just like…
Student 1: Because we thought atoms are probably the basics, the smallest things.
Teacher: So the liquid would look exactly the same?
Student 2: I thought it was kind of like
Student 1: Well, maybe the atoms had to be different.
Student 3: Maybe like spread out more, not like exactly a round shape.
Student 1: Err, and they may not be stuck together, the atoms may not be stuck together, they may be free floating.
Teacher: Draw me a picture of what you think you'll see. [They draw.]
Student 2: So they'd just be kinda like, they'd lose their definite shape.
Student 1: Yeah, they'd lose their…
Teacher: So you're going to have the molecules having kind of different shapes?
Student 2: Yeah.
Student 1: Yeah, and not being stuck together as much as solids.
Teacher: Okay, now he is sticking them together though (refers to a student working on the drawing).
Student 2: Yeah, I think they're stuck together, well it depends, it it's like in a crowded container, they'd probably be together, it's just like
Student 1: They'd have to be together, 'cause what else would there be?
Student 2: Yeah, they'd be…
Student 1: …so they'd always have to be together.
Teacher: So what would distinguish a solid from a liquid if they have to be together?
Student 3: I think the solids would be like more tight in the circles?
Student 1: Well, maybe the liquid (inaudible)
Student 2: I don't know if an atom has a definite shape though, it has like
Teacher: Wait, see what you're doing is you're making that decision, you're deciding what you want it to be, that's what this is all about, what do you want it to be that will explain all of those things up there (points to a poster listing the labs and questions). (Hogan et al., 1999, pp. 405-406).

In this exchange among the teacher and the students, the teacher continues to ask them questions to check the consistency and clarity of their ideas and to reflect their thinking back to them. When the teacher asks a question, the students have an opportunity to support each other's conclusions, build on each other's ideas, and justify their reasoning.

However, Hogan, Nastasi, and Pressley (1999) suggest that teacher-guided discussions can be more efficient in reaching higher-quality explanations but peer-guided discussions tend to be more exploratory, so teachers need to be careful to provide enough guidance to help their students participate in classroom discussions without providing so much guidance or evaluation that they control the classroom discussion and remove the students from their opportunities to construct scientific knowledge and participate in the community of science practice. For example, in Chin and Osborne's (2010) study, the teacher had shown the students how to conduct themselves in student-led, small-group discussions and how to construct arguments and explanations and how to support them with evidence. The following exchange is an example of the student-led discussion within the small groups with the teacher present:

> **Ashley:** A question for you, Dilly. *At what temperature does water evaporate?*
> **Dilly:** 100 [°C]…
> **Lisa:** Because there is a gap there, from the time it's evaporated…
> **Dilly:** Another question. *Does an ice cube melt instantly as soon as it* […]
> **Lisa:** It melts at 0°C, and that's why the line's going straight [flat portion on graph B]…
> **Ashley:** Ice melts at 0°C. And in graph B, it stays at 0 [°C]. As it moves to 1 [°C], it starts to melt.
> **Dilly:** Precisely. *So at what temperature does water [ice] begin to melt? …*
> **Lisa:** *And how long does it take to evaporate? …*
> **Dilly:** Here, it's below 0 [°C]. Here, it goes straight up, Then, it's on 0 [°C]. Here, it's still 0 [°C]. But there is no time. As soon as it gets to 0 [°C], it shoots up…
> **Ashley:** So, as the ice is heated, the heat energy goes into the particles…which will then make them vibrate and change from a solid to a liquid to a gas… (Chin & Osborne, 2010, p. 900, emphasis in original).

However, when the teacher joined the group and started asking questions, the students stopped asking their own questions and constructing their own explanations and started to answer the teacher's questions instead. In the following example, the teacher joined the student small group and began to lead the discussion:

> **Dilly:** Graph B is most likely to show how the temperature of water changes as it heats up…
> **Teacher:** So what are you saying? What is your best bit of evidence? What's the strongest bit of evidence that supports it? It melts at 0 [°C] and boils at 100°C.
> **Lisa:** No.

> **Teacher:** Why do you disagree with that, Lisa?
> **Lisa:** Because… Water freezes at 0°C. It doesn't melt.
> **Dilly:** It does!
> **Lisa:** No, no, wait. Sorry…
> **Teacher:** When substances are heated, the particles in them absorb heat energy and move about more quickly. Does that explain why it stays at constant temperature at 0 [°C] and 100 [°C] though?
> **Ashley:** No.
> **Teacher:** Why not, Ashley?... They absorb energy and move more quickly…when heated.
> **Ashley:** At 0 [°C], it's just starting to melt. And when you heat it up to 1, 2, 3, 4, 5, you can see that the particles are moving more quickly because […]
> **Teacher:** Okay. But why does it not change temperature when it's at 0 [°C]?... I'm not convinced by your argument if you say that as a substance is heated, the particles absorb heat energy and move about more quickly. I'm not convinced that's the best bit of evidence to explain why the temperature doesn't change. You're saying the temperature doesn't change because it's melting. But why doesn't the temperature change when it is melting? (Chin & Osborne, 2010, pp. 900-901).

In this exchange among the teacher and the students, the teacher joined the group, and the teacher's questions limited the student-led, exploratory talk that had already been taking place in the small group. In some cases, these teacher questions may help to guide the discussion and encourage student participation. In this case, however, the teacher's evaluative questions focused on predetermined answers rather than served to elicit student thinking and reasoning. Like the process of a novice becoming a fuller member of the community of practice, with the appropriate scaffolded supports from the teacher (Reiser, 2004; Wood et al., 1976), the students become more comfortable with engaging in classroom discussion. As the students become fuller participants in the classroom discussion, the teacher's scaffolds begin to fade, and the students begin to take on more agency in the classroom discussion, but when the scaffolds return, the students may return to relying too heavily on the teacher's guidance.

Teacher questions as guides in classroom talk. Within classroom discussions, teachers can also scaffold student talk through the use of open-ended questions that prompt students' thinking about what they are studying and their reflection on their own ideas and other students' ideas (Chin, 2007; Chin & Osborne, 2010; Colley & Windschitl, 2016). For example, Chin and Osborne (2010) suggest that providing guidance for students can support them as they engage in productive classroom discussion. By providing initial questions about the phenomenon of the temperature change during the phase change from ice to steam in the previous excerpt, the teacher provided scaffolds for students to ask their own questions (Chin & Osborne, 2010). The teacher suggested questions that the students could consider to start their discussions, such as "What do I notice here?" for the students to think about observing the phase change and the corresponding temperature change; "What questions do I have about this?" for the students to raise questions or other puzzlements about the phenomenon; "What is my explanation for how this happens?" to guide students to construct an explanation about the phenomenon; or "What is the evidence to support my view?" for the students to justify their explanation with evidence from the data and their observations (Chin & Osborne, 2010, p. 907). Within the context of this study, the teachers had provided these and other initial, open-ended questions to guide the small-group, student discussions, but teachers could use these same open-ended questions to initiate and guide whole-class discussions.

While open-ended teacher questions are generally associated with greater student participation in discussion, the type of question and the teacher's follow-up (Nassaji & Wells, 2000) to the student's response can serve to support or hinder a student's participation in the classroom discussion. For example, the following exchange demonstrates an initial teacher question that appeared to be open-ended, but the teacher expected a single answer:

> **Mr. Johnson:** How is an amino acid built? There is a general structure that has to be present for it to be an amino acid. John? (*nods at John*)
> **John:** Isn't it that amino group?
> **Mr. Johnson:** An amino group needs to be present. That's right. (*draws an amino group*)
> **John:** On the left side of
> **Noah:** Of the side chain
> **Mr. Johnson:** On the left side of? (*points at Olivia*)
> **Olivia:** A carboxylic acid
> **Mr. Johnson:** Eh, directly?
> **Olivia:** No (Dohrn & Dohn, 2018, p. 14, emphasis in original).

Depending on the lesson context, the initial teacher question "How is an amino acid built?" could have been open-ended, with possible answers ranging from the structure of the amino acid to the biological processes that generate amino acids. However, when the teacher specified that the exchange would focus on the structure of the amino acid, the initial teacher question was identified as a pseudo-open question (Wellington & Osborne, 2001), in which the teacher expected a single correct answer about the structure of the amino acid. The initial teacher question and the follow-up moves limited the students' responses to closed-ended, factual recall responses. In contrast, sometimes an initial teacher question may be closed-ended, but the teacher's follow-up questions can elicit further student thinking and reasoning. For example, the following exchange describes a discussion among a teacher and a group of kindergarten students:

> **Teacher:** What happened that day a boy grabbed a snail and then you were sad?
> **Pupils (several):** The shell broke.
> **Teacher:** And what did we think?
> **Pupils:** That it would die.
> **Teacher:** And what did we discover?

> **Pupils:** That the shell grew again!
> **Ester:** That with the eggshell the calcium is put in the shell. Because it has calcium.
> **Hector:** Because they eat it [*the eggshell*].
> **Marta:** Yes, and then it is not smashed because it is tougher. (Monteira & Jiménez-Aleixandre, 2016, p. 1249, emphasis in original).

In this example, the initial teacher question asked for a particular response, namely that the snail's shell broke. However, the follow-up questions continued the discussion of the snail's shell with the students, and eventually individual students added additional observations and reasoning about the "not smashed" shell being "tougher" and justifications that the "calcium" from the "eggshell" plays a role in the process of growing the snail's shell again (Monteira & Jiménez-Aleixandre, 2016). Therefore, while the type of initial teacher question is important for encouraging student participation in classroom discussion and eliciting student thinking and reasoning, the teacher talk moves that follow the initial question and that continue to engage the students also determine the opportunities for students to participate in classroom discussion.

Teacher Questioning and Talk Moves

One way for teachers to assist students to engage in classroom discussion is through the specific questions that teachers ask and the corresponding teacher talk moves. In traditional lessons that are teacher-centered, teacher questioning serves "to evaluate what students know," but in constructivist instructional approaches that are student-centered, teacher questioning serves to "diagnose and extend students' ideas and to scaffold students' thinking" (Chin, 2007, p. 818). When used effectively in student-centered instruction, teachers can use questioning to determine what students already know about a concept, to encourage deeper thinking, and to keep track of students' sensemaking around new ideas and new concepts (Weiss et al., 2003). Questioning in teacher-centered instruction instead focuses on questions that elicit factual recall from the students (Weiss et al., 2003). Teacher-student interactions and the questions that teachers use to foster classroom discussion are important for providing students with opportunities to engage in science talk and science practices.

Closed-ended questions and IRE. Teacher-student interactions in the science classroom often fall into the format of a question-and-answer sequence in which the teacher already knows the correct answer and which is used to evaluate a student's comprehension. In these sequences, the teaching purpose typically aligns well with the question-and-answer sequence (Scott et al., 2006), such as when the teacher introduces a new scientific concept or when the teacher checks students' understanding with a question that has a clear answer and does not provide space to discuss why the answer is correct. These types of sequences were originally known as Initiation-Reply-Evaluation exchanges (Mehan, 1979) and later known as a form of triadic dialogue (Lemke, 1990), such as initiation-response-evaluation (IRE). These question sequences are often based on closed-ended questions and typically end in evaluative statements from the teacher. For example, Lemke (1990) describes a classroom conversation in which the teacher asks a closed-ended question and follows up the student's response with an evaluation. The teacher asks, "Can you give me an example of a longitudinal wave?", students call out various responses, and the teacher chooses which response is deemed correct:

> **Teacher:** Yeah! Who said "sound" first?
> **Gary:** Me!
> **Teacher:** Y'did? Alright, Gary, you're right. It's *sound*. Sound wave is a perfect example of longitudinal wave motion. (Lemke, 1990, p. 102, emphasis in original).

The teacher's evaluation tells the student that he is "right." These IRE exchanges typically are brief and use closed-ended questions so that the teacher can focus on the correctness of the student's response (Lemke, 1990). These evaluative statements demonstrate that the teacher exercises control in the classroom. They also tend to limit the amount of student participation in the classroom discussion, so this format for questioning is not conducive to engaging in science talk within the classroom discussion.

Open-ended questions and classroom discussion. The types of questions that teachers use are important in fostering scientific discussion. Teachers' use of closed-ended questions in which the teacher expects a particular answer can hinder classroom discussion while teachers' use of open-ended questions can encourage classroom discussion and promote higher-level critical thinking (Colley & Windschitl, 2016; Erdogan & Campbell, 2008; Martin & Hand, 2009; McNeill & Pimentel, 2010; Oliveira, 2010). In one case, Oliveira (2010) found that open-ended questions were associated with students' responses that were longer and that demonstrated deeper reasoning and higher-level student thinking. These questions also engaged the students as partners in the discussion. In another case, McNeill and Pimentel (2010) found that use of open-ended questions was associated with an increase in students' ability to use both everyday and scientific knowledge to justify their argumentative claims and construct appropriate explanations. For example, the following excerpt displays the classroom discussion about climate change, where the teacher asks an open-ended question toward the beginning of the discussion and the students continue the discussion by introducing their own reasons or building off the reasoning of their fellow students:

> **Jamar:** Maybe the sun is too old.
> **Ms. Baker:** Maybe the sun is too old? You think that has to do with global climate change?
> **Jamar:** It's like dying out.
> **Ms. Baker:** But Sam is saying that in places it's actually not warm it's colder. Or in other in some places too warm in other places it's too cold.
> **Jamar:** It's colder cuz it's dying out.
> **Maria:** It's probably, it's probably the way it's tilting.
> **Alesha:** Yeah, that's why it's tilting like it's in different places.
> **Maria:** Or maybe because it's more um environmentally friendly. That, like that part. Like they say that they get holes in the atmosphere, so maybe where the holes are is above cities that are not so environmentally friendly? (McNeill & Pimentel, 2010, p. 281).

In this example, the teacher asks an open-ended question to the students at the beginning of the discussion, but the students maintain the classroom talk by talking about temperature ("colder"), about the tilt of the sun, or holes in the atmosphere. In the same classroom, the discussions typically focused on student talk rather than exchanges of teacher questions and student responses. Typically, the teacher asked open-ended questions that encouraged students to share their ideas or relate their ideas to those of their fellow students, such as "What do you think?" (McNeill & Pimentel, 2010, p. 222), or open-ended questions that clarified students' comments, such as "Okay. So islands might be under water? Andy why would they be under water?" (McNeill & Pimentel, 2010, p. 222). Further, student responses are typically longer when teachers ask open-ended questions while student responses are typically shorter when teachers ask closed-ended questions (Kaya, Kablan, & Rice, 2014). Therefore, the type of question that teachers ask to engage students in classroom discussion is important.

Types of questions. The primary distinction between the types of questions that teachers use to engage students is between "closed-ended" and "open-ended" questions. Closed-ended questions draw out a limited number of responses (Smith & Hackling, 2016). The responses tend to be limited to yes or no responses or recalling factual or procedural information (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004). These types of teacher-centered, closed-ended questions have been called display or comprehension questions (Oliveira, 2010). For the purposes of this capstone, closed-ended questions also include questions about design decisions or about the set-up or procedure for an activity. Open-ended questions draw out multiple possible responses without any one response being correct or incorrect (Smith & Hackling, 2016). These open-ended questions focus on eliciting ideas, describing observations and data, and constructing explanations (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004). These types of student-centered, open-ended questions have been called referential questions because they refer to students' own thinking (Oliveira, 2010). The various teacher questions serve an important role in engaging the students in the classroom discussion.

Teacher talk moves and classroom discussion. In addition to the importance of the type of question, the teacher talk moves that the teacher employs are also important in engaging students in classroom discussion. A talk move is an utterance, or a unit of talk similar to a word, phrase, or sentence, that gets the other members of a conversation to respond or add to the conversation (O'Connor & Michaels, 2019). The teacher talk moves can be related to how a teacher sets up a question and to how a teacher responds to and follows up with a student response. Typically, the IRE question sequence begins with a closed-ended question and then the teacher evaluates the student's responses as correct or incorrect. However, students are more likely to engage in discussion if the teacher does not evaluate the student's response during the follow-up teacher talk move. Instead, the teacher could engage in an initiation-response-feedback (IRF) question sequence by providing feedback about the student's response or follow-up questions or other types of follow-up prompts rather than evaluative statements (Chin, 2006; Colley & Windschitl, 2016). Teachers can acknowledge students' contributions to the classroom discussion, restate students' responses to clarify students' ideas, or ask follow-up questions that build on students' previous responses and stimulate critical thinking among the students (Chin, 2006). In the following example, the teacher responds to the students using a feedback talk move rather than an evaluative talk move:

> **Teacher:** What are the factors that affect the rate of dissolving? … What do you think? …
> **Student 1:** Temperature of solvent.
> **Teacher:** Temperature of solvent. What else?
> **Student 2:** The rate of stirring.
> **Teacher:** The rate of stirring. How fast you stir it. And also? Yes?
> **Student 3:** The volume of the solvent.
> **Teacher:** Yes. To be more specific, we are talking about size of solute… surface area… What do you observe in daily life that has a relation to the size of solute? (Chin, 2006, p. 1323).

After the teacher asked the initial, open-ended question, the teacher restated and acknowledged each of the first two student responses. After the third student response, the teacher evaluated the student response ("Yes") but then asked a follow-up question about a connection to the students' everyday life to continue the discussion. In each of these cases, the teacher provided the students with some form of feedback to continue the discussion rather than complete the exchange after one student responded. These talk moves tend to help teachers make space for students' thinking and to be responsive to students' ideas (Haverly, Calabrese Barton, Schwarz, & Braaten, 2018). Therefore, talk moves help teachers to provide students with opportunities to access and participate in the classroom discussions.

The classroom discussion should serve as a means for students to participate in the community of science practice, but as novices, students need guidance from their teachers to know how to participate in the classroom talk. Teachers then should lead but not dominate the classroom discussion (Chin, 2006; Fung & Lui, 2016). Teachers should also help to provide opportunities for students' thinking and learning by means of classroom talk and discussion depending on how they combine teacher questioning and teacher talk moves (Chin, 2006; Smith & Hackling, 2016; Tytler & Aranda, 2015). For example, when teachers use open-ended questions and follow-up prompts that challenge their students' claims and explanations and that encourage students to think more critically, provide students with information only when necessary so that students figure out questions on their own, and provide more wait time for students to feel comfortable to respond to questions and engage in the classroom discussion, their students are more likely to challenge and support each other's ideas with evidence and require less guidance than other students (Kim & Hand, 2015). In other words, as teachers challenge their students to deeper and more critical thinking and provide their students with chances to think on their own and participate in science talk with certain types of questions and teacher talk moves, their students need less teacher guidance and begin to participate more fully in the community of science practice. Further descriptions of the types of teacher talk moves are included below.

Types of teacher talk moves. The primary distinction between the types of teacher talk moves that teachers use to engage students is between talk moves that make space for student participation and talk moves that limit space for student participation. As described above, some talk moves are also questions, such as following-up, pressing, or probing questions. The main talk move that limits student participation is “evaluating,” in which the teacher evaluates the student’s response as correct or incorrect (Smith & Hackling, 2016). However, if the purpose of the question-and-answer exchange is to evaluate a student’s response, such as checking for prior knowledge at the beginning of a unit or checking for understanding at the end of a unit, then the evaluation talk move aligns with the instructional goals (Scott et al., 2006). An affirmation or positive evaluation would evaluate a student’s response as correct while a negative evaluation would evaluate a student’s response as incorrect (Tytler & Aranda, 2015).

The following talk moves serve to make space for student participation in the classroom discussion. “Acknowledging” a student’s response recognizes or accepts a student’s response without positively or negatively evaluating the response (Smith & Hackling, 2016; Tytler & Aranda, 2015). “Pressing” involves asking a student to elaborate on an idea; to more fully construct an explanation; to provide further evidence; or to present ideas, observations, or personal experiences to the class (Smith & Hackling, 2016; Tytler & Aranda, 2015; Windschitl et al., 2018). A teacher presses a student to go further with an idea or an explanation, such as when a teacher asks a student, “What do you mean by that?” (Martin & Hand, 2009, p. 34). “Following up” on a student’s response can often mean asking a question that centers on a student’s idea or providing scaffolded cues to prompt or assist a student in creating a response (Smith & Hackling, 2016; Windschitl et al., 2018). “Restating” involves the teacher’s restating the student’s response or the teacher’s asking the student to restate the response (Smith & Hackling, 2016). “Revoicing” means identifying the importance of all or part of a student’s idea, such as by rephrasing how the student expresses the idea or by relating the student’s everyday language to appropriate academic language (Tytler & Aranda, 2015; Windschitl et al., 2018). “Focusing” involves asking the students about a part of complex procedure, representation, or model (Windschitl et al., 2018). “Rephrasing the question” generally occurs after students do not answer the teacher’s question or do not understand the teacher’s question and involves re-framing the question or asking the question again using different words or with an example to contextualize it (Smith & Hackling, 2016; Tytler & Aranda, 2015; Windschitl et al., 2018). “Opening up cross-talk” means prompting or encouraging students to talk to each other (Windschitl et al., 2018).

Types of student responses. The types of student responses tend to correlate to the type of initial teacher question. A closed-ended question tends to receive a “closed-ended response” or a narrow response, in which the responses are shorter and limited to yes/no, factual recall, design decisions, and activity procedures and materials (Chin, 2006; Smith & Hackling, 2016). Responses to open-ended questions are typically longer and not limited to correct or incorrect answers and so are “open-ended responses” or broad responses. “Description” means that students describe or depict current or previous observations of objects or events (Smith & Hackling, 2016). “Explanation” involves students explaining or clarifying an idea or process (Chin, 2006; Smith & Hackling, 2016). “Reasoning” means providing a scientific reason or evidence to justify a claim, explanation, or argument (Chin, 2006; Smith & Hackling, 2016). “Prediction or Hypothesis” involves making predictions about what may happen next, such as in an activity (Chin, 2006; Smith & Hackling, 2016). “Reply” means one student responds to another student (Chin, 2006). The student's reply could be categorized as a narrow response that refers to a yes/no response, factual recall, or activity procedures or as a broad response that refers to description, explanation, prediction, or reasoning.

Chapter Summary

This chapter focused on my review of literature related to the science practices, classroom discussions, and the connected topics of teacher questions, teacher talk moves, and student responses. My problem of practice aims to address how to encourage student participation in science talk. Students do not always have access to science talk, and when they do, they may not know how to engage in it. Teachers can serve as facilitators for these students, providing them with opportunities to talk like scientists through classroom discussions and encouraging them to participate in classroom discussions through questioning and talk moves. This chapter showed how the science practices are based in discussion and how students often learn science through talk and discussion. This chapter also showed what talk looks like in teacher- and student-centered classrooms and how different types of teacher questions and talk moves can hinder or encourage student participation in classroom discussion. This chapter ended with descriptions of the different types of teacher questions, teacher talk moves, and student responses. A rich study of these questions, responses, and talk moves in question-and-answer sequences within the context of classroom discussions might identify which teacher questions and talk moves are present and provide opportunities for student response.

CHAPTER 3: METHODS

The purpose of this study was to explore the kinds of questions that teachers asked within an integrated STEM curriculum. This capstone addressed the following research question:

(1) What kinds of teacher questioning and opportunities for student response are present in the discussions during the enactment of the SPICE curriculum?

   a. In whole-class discussions, what is the frequency of teacher questioning as compared to student response?
   b. In whole-class discussions, to what extent do frequency and kind of teacher questioning and student response differ by lesson?
   c. In whole-class discussions, what kinds of questions do teachers ask, and what kinds of student responses do these questions elicit?

To address this research question, this chapter describes the research study design, the study site and participants, the data sources and methods for data analysis, the role of the researcher, the attempts to establish credibility and trustworthiness, and limitations of the research study.

Research Design

The research design that was used is a descriptive case-study approach (Yin, 2017) to describe and analyze the patterns of teacher questioning within the context of the SPICE curriculum as it had been implemented at one elementary school. Case studies are “in-depth and detailed explorations of single examples” and “focus on the particular” (Rossman & Rallis, 2017, p.91), and they assume long-term and close-up examination of practices to understand a phenomenon (Yazan, 2015). The case is bounded by the amount of time used to study the case and the phenomenon of interest (Creswell, 2014), and a case study is especially useful when the boundaries between the phenomenon of interest and the context are not clear (Yin, 2017). The unit of analysis in this case was the sequence of the teacher question and the student response, which was a focus of the context of the SPICE curriculum, and the case was bounded by the length of the implemented unit.

Context of the Larger Study

The SPICE project focused on creating curricula for elementary and middle school classrooms that use computational thinking activities to make connections between science and engineering. The SPICE curriculum aimed to utilize and make connections among computational thinking, scientific reasoning, and engineering design together through computational modeling within an earth science unit (Chiu et al., 2019). The four-week, NGSS-aligned project was developed to engage students in an authentic engineering problem grounded in their own school context (Chiu et al., 2019), and the science and computational thinking lessons were included in service of the engineering content. The unit challenged students to redesign their school to reduce water runoff through hands-on investigations about the relationships among rainfall, absorption, and runoff as well as creating computational models to test their design solutions. The curriculum divided into ten separate lessons (Table 3.1), which included a variety of tools to represent scientific relationships and help students develop their design solutions.

Table 3.1
The SPICE lessons including discipline and focus

Lesson	Discipline	Focus	Number of Sub-Lessons or Activities	Expected Time of Lesson
1	Engineering	Defining the problem	6	1 hour
2	Science	Eliciting students' prior knowledge about runoff and absorption	2	1 hour
3	Science	Investigating the relationship between intensity, time, and quantity of rainfall	7	1 hour
4	Science	Investigating the relationship between surface material and absorption	6	1 hour
5	Science	Investigating surface slope's impact on absorption	6	1 hour
6	Engineering	Designing solutions to the schoolyard runoff problem	3	1 hour
7	Computational Modeling	Developing a computational model to be able to test the effectiveness of the solutions for solving the problem	4	5 hours
8	Engineering	Developing additional solutions to test using the computational model and comparing solutions	4	1 hour
9	Engineering	Using the computational model to test solutions and iteratively improve them	4	2 hours
10	Engineering	Developing and delivering a report that argues for a particular design solution	1	2 hours

Science-focused lessons. The main purpose of these lessons was to develop students' understanding of the concepts of rainfall and of the movement, the absorption, and the runoff of rainfall. In this regard, these lessons focused on teaching scientific concepts in the service of the water runoff engineering design project. The four science-focused lessons (i.e., Lesson 2, Lesson 3, Lesson 4, Lesson 5) and the corresponding curricular activities are described below.

Lesson 2. Lesson 2 lasted one class meeting each for the morning and afternoon sections. The teachers began Lesson 2 with a review of the engineering design challenge. The teachers led a discussion of what models are and the different kinds of models, such as scientific, physical, and conceptual models. For this lesson, the models that the students generated were meant to be predictive and not final and so were considered works in progress that could be re-evaluated and revised throughout the project. Through revising their models based on new and changing information, the students acted like scientists. The students began to create conceptual models showing where the water comes from and where the water goes when it rains. The teachers also demonstrated the structure of the models and the process of creating the models within the computer program (e.g., using arrows to represent the amount and movement of water). The lesson ended with the students comparing the models that they generated.

Lesson 3. Lesson 3 lasted five class meetings for the morning section and four class meetings for the afternoon section. The teachers began Lesson 3 with a discussion of amount and intensity of rainfall (e.g., heavy versus light rainfall, high versus low hourly rainfall rate, rainfall duration). The teachers then introduced the investigation activity and the materials and instruments (e.g., rain gauges, cups, stopwatches) to the students. The teachers modelled the investigation first before the students gathered the data. The focus of the investigation was on duration of rainfall and its effect on the total amount of rainfall. After the teachers and students engaged in a discussion of the differences in the videos of light and heavy rainfall, the students calculated the amount of total rainfall based on hourly rainfall rate and rainfall duration and discussed the multiplicative relationship between hourly rainfall rate and rainfall duration to calculate amount of total rainfall. The students discussed a data table with past data of the average hourly rainfall at the school and considered the past data when they discussed how much hourly rainfall their designs should withstand. The teachers then introduced the students to argumentation or scientific explanation and the components of claim, evidence, and reasoning. The teachers led the students through a discussion of the relationship among total rainfall, hourly rainfall rate, and rainfall duration through the lens of claim, evidence, and reasoning. Lesson 3 concluded with the students revising their models and discussing any changes that they made.

Lesson 4. Lesson 4 lasted three and a half class meetings for the morning section and four and a half class meetings for the afternoon section. The teachers began Lesson 4 with a discussion for the students to use their prior knowledge about rainfall and about water that collected in the recess area at the school to make predictions about where water goes when in contact with different materials (i.e., grass, concrete). The students investigated the absorption of water by different materials and discussed their observations from the investigation activity. The teachers then introduced new vocabulary (i.e., absorption, permeable, impermeable), and the students used these terms to describe their observations from the investigation activity and to explain why concrete absorbed less water than grass. The students examined a data table that described different surface materials and their absorption ratios and discussed what surface materials should be used in their designs. The students used absorption ratio and total rainfall to calculate the total amount of water absorbed by the surface materials. The teachers led the students through a discussion of the scientific explanation for the relationship among amount of total rainfall, absorption ratio, and amount of total absorption. Lesson 4 concluded with the students revising their models and discussing any changes that they made.

Lesson 5. Lesson 5 lasted two and a half class meetings for the morning section and one and a half class meetings for the afternoon section. The teachers began Lesson 5 with a classroom discussion about a video that focused on water runoff as a problem and ways to reduce runoff. The students used their prior knowledge and personal experiences to make predictions about the relationship between the slope of a surface and amount of water runoff. The students conducted multiple trials of an investigation on slope and then discussed the collected data of changes in slope and changes in amount of water runoff and the patterns within that data. The teachers and students discussed explanations for why high slope was related to more water runoff and calculated runoff based on the absorption ratios of different materials and different amounts of total rainfall. The teacher led the students through a discussion of the scientific explanation for the relationship among amount of total water runoff, amount of total water absorption, and amount of total rainfall. Lesson 5 concluded with the students revising their models and discussing any changes that they made.

Similarities and differences among science-focused lessons. Looking at the similarities and differences among the lessons, the four science-focused lessons seemed to follow a similar structure. In general, each lesson had a different objective (i.e., where the rain goes; how duration and intensity affect the amount of rainfall; absorption and different surface materials; factors affecting runoff), and the teachers and students discussed the different concepts for each lesson's objective throughout the particular lesson. Lesson 2 was different from the other lessons in three respects: (1) there was no corresponding investigation activity in Lesson 2 while there was one in the other three lessons, (2) the students engaged in scientific argumentation and developed claim, evidence, and reasoning statements in the other three lessons but did not engage in formal argumentation in Lesson 2, and (3) the students created their water runoff design models in Lesson 2 while they revised their models and discussed the changes that they made in the other three lessons.

Context of the Current Capstone Project

School district and school. The site for this capstone project was a small, suburban school district, in the southeastern United States: Spring City Public Schools (SCPS; pseudonym). This district had large populations of students who qualified for free or reduced-price lunch (53% of students) and who were from backgrounds traditionally underrepresented in STEM (e.g., 38% of the students were Black; 13% of the students were Hispanic). The SCPS district included six elementary schools and three secondary schools. Two of the elementary schools were conditionally accredited while the other schools in the district were all accredited (State Department of Education [SDOE], 2019a). The focus of this capstone project was on one fifth-grade classroom within Brooks Upper Elementary School (BUES; pseudonym), which served both fifth and sixth grades.

Approximate demographic data for SCPS and for BUES are presented in Table 3.2 (SDOE, 2019b). The approximate demographic data for three school districts of similar sizes to SCPS are also presented in Table 3.2 (SDOE, 2019b). These data are presented with approximate values to limit the identifiability of these districts. The demographic data suggested that the district as a whole and the school in particular had

Table 3.2
Demographic data for Spring City, Thunder City, Red City, and New City Public Schools districts and for Brooks Upper Elementary School, Fall 2018

	Spring City Public Schools District	Brooks Upper Elementary School	Thunder City Public Schools District	New City Public Schools District	Red City Public Schools District
All Students (N)	~4600	~660	~5700	~4400	~7700
Black	32%	38%	68%	12%	10%
Hispanic	12%	13%	9%	38%	66%
Asian	7%	6%	1%	2%	3%
White	41%	38%	19%	40%	15%
Other Races	n/a	n/a	<1%	<1%	1%
Two or More Races	9%	5%	3%	8%	5%
Economically Disadvantaged	44%	53%	56%	49%	50%
English Learners	13.5%	16.6%	5.8%	21.2%	48.7%
Students with Disabilities	13.1%	18.3%	13.4%	10.5%	12.5%

similar percentages of students based on racial/ethnic groups. However, BUES appeared to have higher percentages of economically disadvantaged students, English learner students, and students with disabilities than SCPS district as a whole. When compared to other school districts within the same state in Table 3.2, the demographic data were different, even among school districts of similar sizes. This lack of similarity of the demographic data across school districts suggested that the findings from this study might not be transferable to other school districts even if the findings might be transferable from BUES to SCPS district, but this lack of transferability can be expected with a case study.

In addition to the demographic data, examining the average pass rates for the Standards of Learning (SOL) end-of-course tests for mathematics and science could also be useful, especially considering the focus of the SPICE curriculum on integrating

Table 3.3
Pass rates for Grade 5 Science and Grades 5 and 6 Mathematics SOL end-of-course tests for Brooks Upper Elementary School from 2015-16 through 2017-18

	2015-16	2016-17	2017-18
Grade 5 Science			
All Students	67%	68%	61%
Female	67%	67%	62%
Male	67%	69%	60%
Black	45%	46%	43%
Hispanic	65%	61%	50%
Asian	59%	60%	65%
White	94%	88%	83%
Economically Disadvantaged	49%	50%	44%
English Learners	50%	57%	40%
Students with Disabilities	25%	39%	26%
Grades 5 and 6 Mathematics			
All Students	74%	75%	70%
Female	75%	77%	70%
Male	73%	73%	70%
Black	54%	57%	50%
Hispanic	74%	73%	67%
Asian	88%	79%	76%
White	92%	91%	86%
Economically Disadvantaged	61%	61%	55%
English Learners	76%	74%	67%
Students with Disabilities	37%	38%	35%

science, engineering, and computer science. These average pass rates demonstrated student achievement in related content areas. Table 3.3 displays average pass rates for the Grade 5 Science and the Grade 5 and 6 Mathematics SOL end-of-course test administrations for Brooks Upper Elementary School for the 2015-2016, the 2016-2017, and the 2017-2018 academic years (SDOE, 2019c). The data demonstrated low pass rates (i.e., below 70%) for most students. Black and Hispanic students did not perform as well on the SOL end-of-course tests in mathematics as White and Asian students, and no racial/ethnic group performed as well as White students on the SOL end-of-course tests in Grade 5 science. In addition, economically disadvantaged students, English Learner students, and students with disabilities had low pass rates in mathematics and very low pass rates in Grade 5 science, except for English Learner students on the mathematics tests in the 2015-2016 and 2016-2017 academic years. Examining these average pass rates provided an understanding of the students' average level of mathematics and science knowledge at BUES over the course of the three academic years before the implementation of the SPICE curriculum.

Participants (teachers and class sections). This study examined two fifth-grade class sections of science taught by one female teacher. A male SCPS STEM specialist involved with the SPICE project also participated as a co-teacher during the SPICE implementation. Both teachers had undergraduate degrees in life science. Both teachers had at least seven years of K-12 teaching experience. The classroom teacher had previously taught three years at BUES while the STEM specialist was in his first year at the school. The classroom teacher typically taught science every day of the week. The STEM specialist typically taught science three days of the week, but he attended most of the class meetings during the implementation of this SPICE unit. The unit was taught in two different fifth-grade class sections, and the teacher and STEM specialist taught the unit to both sections. Both fifth-grade class sections had 28 students. One fifth-grade section (i.e., the morning section) had more students with individualized education programs (IEPs), and the other fifth-grade section (i.e., the afternoon section) had more students who were enrolled in advanced mathematics. This research study focused on both sections but aggregated the findings from both sections to generate a more complete view of teacher questioning and student talk during the implemented SPICE unit.

Data Sources and Data Collection

The primary data source for this capstone study was the collection of audio transcripts of the whole-class discussion during the SPICE curriculum implementation. Analysis of multiple data sources can establish credibility of the research findings through data triangulation (Rossman & Rallis, 2017; Yin, 2017), but when using a single data source then investigator triangulation through the use of multiple evaluators can support credibility as well (Yin, 2017).

Audio transcripts. Each class meeting was video recorded using two separate video cameras, and each video camera was positioned behind one of the tables at which the students sat. The video cameras were placed in the same position behind the same table for each class meeting. The students generally sat at the same tables throughout the unit. Different numbers of sub-lessons were covered during each class meeting, with some sub-lessons taking more than one class meeting, lesson than one class meeting, or exactly one class meeting to complete, so multiple sub-lessons were sometimes completed in a single class meeting. Each class section completed the unit in 22 class meetings. The focus of this capstone was on the science-focused lessons, and the morning section completed the science-focused lessons over 12 class meetings while the afternoon section completed the science-focused lessons over 10 class meetings.

Each video recording lasted approximately 45 minutes and captured classroom talk during the time before students began to enter the classroom, the time at the beginning of class before the lesson began, the lesson proper, and the time after the end of the class meeting. The video recordings were then converted into audio recordings and were initially transcribed using the website Rev.ai. After the initial, computer-generated transcriptions were returned, six research team members corrected the computer-generated transcripts, with one research team member correcting most of the transcriptions. When teacher talk or student talk was deemed inaudible, the audio file was first reviewed and then corrected. If the teacher talk or student talk was still inaudible, then the surrounding lines of talk were considered to make sense of the teacher talk or student talk. For example, the teachers restated student responses sometimes, and the teachers' restatements were used to determine the student's response. If the line of talk was still inaudible due to the low speaker volume or due to multiple speakers speaking at the same time, then the line of talk remained "inaudible."

Data Analysis

Data analysis for this research study occurred primarily through coding using the qualitative analysis software Dedoose and Microsoft Excel. The coding process occurred in three phases in order to focus the coding on teacher questioning within the SPICE curriculum. Descriptive quantitative analyses were conducted with Microsoft Excel.

Provisional codes. The first round of coding utilized provisional coding, or a beginning list of potential codes generated by the researchers (Saldana, 2016). The initial coding focused on the whole-class discussion. A team of three researchers worked together to develop an initial code list that was revised and modified through an iterative process of discussion after independently coding two transcripts of the whole-class discussion. The coding focused on distinguishing among the different types of teacher talk within the whole-class discussion. The unit of analysis for the teacher line of talk was determined to be a sentence or phrase. After coding three transcripts, the three coders met after coding each transcript, discussed changes to the code list, and reached agreement on the differing codes by consensus. After coding two more transcripts, the inter-rater reliability was determined to be greater than 80%. At this point, the individual coders began to code the transcripts independently. An additional coder also began to participate in the provisional coding. This coder began by coding the first five transcripts that were used by the provisional coding team to establish inter-rater reliability. The provisional code list is included in Appendix A.

Descriptive codes. The provisional code list was used to identify portions of the whole-class discussions that related to teacher questioning and student responses. The descriptive codes were used to describe the types of teacher questioning and the elicited student responses in more detail. Each couplet of a teacher question and student response or of a teacher talk move and student response was coded. The teacher questions were coded using categories that illustrate the openness of the question. The student responses were coded using categories that describe the type of response. The code list was drawn from observations of the transcripts made during the provisional round of coding in order to describe the types of teacher questioning more fully. Additional codes were also drawn from the literature (e.g., Chin, 2006; Smith & Hackling, 2016; Tytler & Aranda, 2015; Windschitl et al., 2018) and included descriptions of the types of questions (e.g., open-ended questions, closed-ended questions), the types of talk moves (e.g., evaluating, pressing, following up, restating), and the types of student responses (e.g., factual recall, description, explanation). This *a priori* code list is included in Appendix B.

Determining the question sequence. The descriptive coding took place in multiple steps. The first step was separating the transcript into chunks or sections that became the question sequences. Each chunk or question sequence was defined as bounded by a single concept or instructional goal. It began with a lead-up statement (e.g., activating prior knowledge, providing background knowledge) that led into the initial question or began directly with the initial question. The initial question opened the discussion on that concept or instructional goal, and the final statement closed the discussion on that concept or instructional goal before the classroom discussion moved on to another concept or instructional goal and another question sequence. The initial question may be divided into multiple sentences or phrases, including the lead-up statements. The teacher may ask the initial question multiple times or in multiple different ways before the students responded or were able to respond. The question sequence included at least one initial question to which the students were able to respond and the student response that was a phrase, statement, or sentence that served as a response or answer to the teacher's question. Typically, there was also a teacher follow-up that was in response to the student response. This follow-up may be a restatement of the student's response, an evaluation of the student response, etc., but it generally was conceptually or contextually related to the student response. The follow-up may also connect further with the student response by asking another question, which may be a follow-up question that furthered the conceptual discussion or that was related to the overall concept or context of the question sequence while asking a question that took the question sequence down a related but different path.

The question sequences were sections of the classroom discussion that related to the purpose of teacher questioning (e.g., review, setting up an activity, defining a new vocabulary term). The sequence of dialogue typically began with an initial question or with the teacher providing background information or activating prior knowledge. These sequences continued with exchanges of teacher talk and student talk until the teacher made a summative statement, began a new activity, or asked a new question that signaled the start of a new question sequence with a different conceptual purpose. For the transcript data for each class meeting, these question sequences were determined before any additional coding occurred. Each transcript was read, and short descriptions of each question sequence were written. After the sentence-level coding and couplet-level coding were completed, the descriptions of each question sequence were collected to determine patterns among question sequences and to assign them to categories. Sometimes, question sequences were separated into two or more different question sequences when appropriate, such as separating the question sequence that examined patterns and making conclusions about data from the original question sequence that focused on classroom discussions about data and observations.

In addition to the discussion-related talk, there were also opportunities for non-discussion-related talk. These instances typically included logistics talk, such as classroom management; teacher talk directing the students how to conduct a procedure for an activity; or telling information, such as providing content instruction that was not directly related to the discussion or question sequence. These statements were not included as part of the exchanges of questions and responses and so were considered separately from the discussion-related teacher talk and student talk. However, if these statements took place during the course of a question sequence, then they were considered separately from the discussion-related talk but were included in the full picture of the question sequence.

In situ positional coding. The in situ positional coding was applied to distinguish the different types of discussion-related teacher talk from the student talk. The teacher talk was labeled as a lead-up statement or initial question to signal the beginning of a question sequence or as a follow-up statement. The student responses were identified as student talk.

Applying descriptive coding. Using the *a priori* codes from Appendix B, the descriptive coding then took place. The initial questions were identified as one of the teacher questions. The follow-up moves were identified as talk moves if the follow-up moves were related to the student response or asked the student to think more deeply about the question, or they were identified as open or closed questions if the teacher asked new questions that were different from but still related to the initial question. The student responses were identified as one of the types of student responses based on a yes/no response, factual recall, recall of an activity procedure or design decision, an elicited idea, a prediction or hypothesis, a description, or an explanation or reasoning.

Determining turns of talk. For most of the quantitative analyses, turns of talk were used. The turns of talk were determined based on a change in speaker from teacher to student, from student to teacher, or from one student to a different student. During the implementation of the SPICE curriculum in both sections, both the classroom teacher and the STEM specialist attended most of the class meetings, with at least one of them attending each of the class meetings. While at least one researcher was always present during each class meeting, the classroom teacher (i.e., Ms. Fisi; pseudonym) and the STEM specialist (i.e., Mr. Quim; pseudonym) led the classroom talk and were the primary speakers, and the researchers rarely spoke during the classroom discussions and did not speak during most class meetings. Since the classroom teacher and the STEM specialist often both spoke in each class meeting rather than separating their classroom talk by lesson (e.g., alternating leading different lessons), their classroom talk was considered as a single category of teacher talk rather than separating their talk into different categories, such as "classroom teacher talk" and "STEM specialist teacher talk." Additionally, while multiple students participated in the classroom discussions, their responses were considered in aggregate when analyzing the data rather than considering students' responses individually. Different students were also determined based on their voices from the audio files. Finally, both class sections (i.e., morning, afternoon) were examined, and the findings for the classroom talk were reported in aggregate.

Since the descriptive codes were applied at the sentence level, when the turns of talk were determined, there were multiple codes applied to a single turn of talk, typically for teacher talk. To address this issue, there was a priority of applying the descriptive codes to the turns of teacher talk. The initial question, including any lead-up statements, was assigned as either an open question or a closed question. For the follow-up codes, they were assigned according to the following priority: (1) open question or closed question (if there was a new question that was still related to the overall purpose of the question sequence and did not signal the start of a new question sequence); (2) following-up or pressing talk moves (if the follow-up question was still related to the initial question and if the teacher asked the student to elaborate or make other connections); (3) restating talk move (which was applied as needed when the teacher did not hear the student or if the teacher asked the student to repeat the response); (4) nominating talk move (which was applied at a lower priority than the above teacher questions or talk moves, so even if the nominating talk move directly preceded the student response, the teacher turn of talk was associated with the corresponding teacher question or talk move before being associated with the nominating talk move, and this distinction means that when a student response is associated with a nominating talk move, the implication is that the teacher is asking the students for multiple responses to a single teacher question rather than a new teacher question that expects a new line of student response); and (5) the other talk moves, including acknowledging and evaluating (since these talk moves were either subsumed into the higher priority teacher questions or talk moves or were not associated with eliciting student responses and instead provided a kind of feedback that typically occurred at the end of a question sequence). With this process, each turn of talk was assigned only one code.

Pattern codes. After the transcripts were coded according to descriptive coding, these sequences of teacher questioning and student responses were grouped together as sections of dialogue that relate to the same type of teacher questioning, specifically as a sequence of dialogue that began with an initial question and continued with student and teacher responses until the teacher asked a new question, the teacher made a summative statement, or the teacher began a new activity (e.g., Hogan et al., 1999). These sequences of dialogue or question sequences were examined to determine patterns of similar data (Saldana, 2016) with regard to the types of teacher questioning and corresponding student responses. These question sequences were determined during the first step of assigning the descriptive coding.

Analytic memos. During all rounds of coding, I recorded analytic memos, which helped to keep track of a researcher's thoughts about the data and analyses and provided ways to summarize and synthesize the data into more developed meanings (Miles, Huberman, & Saldana, 2014). One set of these analytic memos was directly tied to the data and was recorded primarily during the coding process. A second set of analytic memos was recorded separately from the data and helped to make sense of the data and to organize my thoughts regarding patterns that began to emerge during the coding and additional analyses. Analytic memos were also used to keep track of frequency counts and data summaries during the descriptive coding and the pattern coding.

Discussion patterns. To address the first and second research sub-questions, I counted the frequencies of the teacher questions, other teacher talk moves, and student responses in each class meeting as captured in the audio transcripts of the whole-class discussions. For the first research sub-question, these frequency counts of teacher questions, teacher talk moves, and student responses were compared to each other directly. The following percentages were calculated: (1) percentage of teacher questions out of total turns of talk, (2) the percentage of teacher talk moves out of total turns of talk, and (3) the percentage of student responses (both directly related to teacher talk and not directly related to teacher talk) out of total turns of talk. The student talk that was not directly related to teacher talk was also coded interpretively to determine trends.

The second research sub-question addressed differences of teacher questions from the individual science-focused lesson of the SPICE curriculum. To address this sub-question, the following percentages were calculated: (1) percentage of teacher questions out of total turns of talk within each lesson, (2) the percentage of teacher talk moves out of total turns of talk within each lesson, and (3) the percentage of student responses (both directly related to teacher talk and not directly related to teacher talk) out of total turns of talk within each lesson. The student talk that was not directly related to teacher talk was also coded interpretively to determine trends within each lesson.

The third research sub-question addressed the relationship between the kinds of questions that teachers asked and the kinds of student responses that were elicited. Based on the types of teacher questions, types of teacher talk moves, and types of student responses as described in the descriptive codes, the teacher talk and student talk were considered as couplets or pairs, with the teacher question or teacher talk move paired with the corresponding student response as a couplet. These couplets were then coded interpretively based on different categories according to the student responses. These categories included yes/no, recall, design, describing, predicting, explaining, and reasoning (Chin, 2006). These categories were then described in further detail within the context of the lesson. Other couplets were also coded interpretively, including teacher questions that elicited student questions as responses. In addition, how teachers reacted when students did not respond to the teacher question was also analyzed interpretively. Finally, since the question sequence often extended beyond the couplet of one teacher turn of talk and one student turn of talk, the question sequences were analyzed interpretively. The question sequences included multiple teacher and student responses and were bounded by a single conceptual sequence or instructional goal as described in the pattern codes. Analyzing these question sequences demonstrated that the context of the whole-class discussion was also important in understanding the flow of teacher questioning and student responses (Mercer, 2004). For example, while a teacher may initiate a classroom discussion with a closed-ended question, the teacher may scaffold or guide participation in the classroom discussion through subsequent questions and other talk moves so that the students eventually engaged in science talk with one another with minimal input from the teacher. However, that question sequence might not have been examined if the analysis ended with the initial, closed-ended question. Therefore, analysis of question sequences provided information that complemented the analysis of types of questions and types of student responses in aggregate and in individual lessons.

Establishing Credibility and Trustworthiness

To establish credibility and trustworthiness with a single data source (i.e., transcripts of audio recordings of the whole-class discussions), I employed investigator triangulation (Yin, 2017) with multiple evaluators. Engaging other members of the SPICE research team as critical colleagues allowed for greater reliability to be established for the coding scheme and the application of codes. The provisional rounds of coding occurred with team members so that inter-rater reliability could be established. Further, the other members of the SPICE research team also served as critical colleagues who helped to evaluate codes, themes, and assertions as they emerged from the data. Unfortunately, I was not able to employ member-checking with the participating teacher and STEM specialist to corroborate their contributions and to substantiate my interpretations and analyses to further establish credibility and trustworthiness during this round of the analysis, but I will attempt to work with them at a later time.

Researcher’s Role as Instrument

Researcher reflexivity. In addition to addressing trustworthiness through research methods, it is also important to consider the relationship between my own experiences and my role as a researcher in this qualitative research study. Presently, I am a graduate student at a large, research-focused university in the southeastern United

States. Previously, I had earned a master's degree in education as part of an alternate route certification program that worked exclusively with Catholic schools. Through this program, I taught primarily high school chemistry and middle school physical science for four years in Dallas, Texas, in a highly diverse Catholic school whose student population was approximately 30% White, 35% Hispanic, 30% Black, and 5% Asian.

Having primarily taught science content, I am committed to research in science education and to the implementation of best practices in science education, but I also recognize the importance of making connections among all of the STEM content areas to promote the interconnectedness of science, technology, engineering, and mathematics. In the classroom, I focused much of my instruction on teacher questioning, especially to lead students to make their own conclusions and to provide evidence for their thinking. Further, I have recently become interested in communication, especially communication and discourse within the science classroom. The focus on teacher questioning in my instruction and my recent interest in communication and discourse within the science classroom related well to the present research study. However, I only recently started to work with the SPICE project, and I did not collect the data or visit the research sites. Further, my teaching experience mainly involved creating my own curriculum rather than following an existing curriculum. These factors can potentially influence my analysis of the data. For example, having taught in a private school and having created my own curriculum, I was able to focus my lessons on what I considered to be most important rather than follow a set curriculum. Even though the teacher and STEM specialist attended a SPICE professional development before enacting the curriculum, I need to remember that the teacher and STEM specialist might not have been as comfortable enacting a curriculum that they did not create themselves and with which they were less familiar. Also, since I did not collect the data, I relied on other sources, such as SPICE team members who had collected the data or video recordings of the lessons, to understand the context of the site and the nuances of the implementation of the unit. Therefore, it is important to reflect on my own experiences throughout the analytic process to further establish trustworthiness in the research findings.

Finally, it is also important to reflect on the relationship between the case study research design and the paradigmatic perspective through which the analysis was conducted. Recognizing the goal of interpretive qualitative research as the search for multiple truths, I subscribe to portions of post-positivist and of constructivist and interpretivist paradigms. My physical science background informs my post-positivist belief in one reality, but the research to understand this one reality is imperfect and unfulfilled (Guba & Lincoln, 1994). However, each person interprets this reality individually. People influence and change the world based on their interpretations of reality. Focusing on context and interpretation, I also subscribe to a constructivist or interpretivist paradigm (Guba & Lincoln, 1994). In my view, the post-positivist paradigm applies to non-human situations while social research is guided by descriptive interpretivism. Recognizing these two sides of my worldview, I ultimately subscribe to a pragmatic paradigmatic perspective since the truths that arise from research are not solely within the mind and not solely separate from the mind (Creswell, 2014). Pragmatists recognize that research happens in social contexts that are influenced by history and politics (Creswell, 2014), and these considerations align well with research into the discourse between teachers and students within the context of the implemented SPICE curriculum. Although Creswell (2014) notes that the pragmatic perspective is most closely related to mixed methods research, the focus of the pragmatic perspective is on addressing and understanding the research problem (Creswell, 2014), which aligns well with addressing a problem of practice.

Researcher as instrument. Since I only recently started to work with the other researchers on the SPICE project, I was not involved with the creation of the SPICE curriculum, the implementation of the curriculum within the classroom, or the data collection process within the classroom. Therefore, my own experiences and biases did not affect or guide any of the data collection. However, my lack of presence in the field can inhibit my understanding of the classroom context, which may in turn be reflected in the data analysis. Due to these limitations, my data analysis focused on the transcripts of the audio recordings of the whole-class discussions as they represented the most complete record of the classroom implementation of the curriculum. Further, it is important that I engage other members of the SPICE research team as critical colleagues throughout the data analysis process and that I conduct member-checking with the participants.

IRB Considerations

Since this study occurred as part of a larger research project, the principal investigator of the larger research project has already received approval from the institutional review board (IRB). The principal investigator of the larger project, Dr. Jennifer Chiu, will serve as a co-chair of my capstone committee. My advisor, Dr. Julia Cohen, will serve as the other co-chair of my capstone committee. The third member of my capstone committee will be Dr. Sarah Fick. There are no anticipated risks as part of the current capstone study. I plan to use pseudonyms for the names of participants and places to maintain confidentiality. All data sources will be secured with a password-protected University of Virginia Box account, a password-protected Dedoose account, and a password-protected computer. Only other researchers on the larger project have access to the data sources.

Chapter Summary

This chapter began with a re-statement of the purpose of this capstone study and the research question to provide a starting point for discussing the research methods undertaken in this study. I explained the research design and briefly described the context of the larger SPICE study. Then, I described the context of the site and the participants for this research study. Next, I described the primary data source that was used for the study and the method for data collection, which was followed by a description of the provisional, descriptive, and pattern coding processes of the data analysis. Finally, I described the efforts that I took to establish trustworthiness and credibility in the study, my role as a researcher, and the limitations of the research study.

CHAPTER 4: FINDINGS

The purpose of conducting this research study was to examine teacher questioning and opportunities for student responses as part of whole-class discussion within a classroom setting during the enacted SPICE curriculum. On a broader scale, the SEPs are language-intensive, and students can participate in science and engage with the SEPs through classroom talk, such as classroom discussion (Lee et al., 2014; NGSS Lead States, 2013, Appendix F). On a more focused scale, the district's teachers and administrators intend for the district's integrated-STEM program to promote access for all students to STEM content areas (School District, n.d.), such as through engaging in science talk. In particular, the teachers and administrators focus on exploring how teachers use questioning to support students' engagement in the SEPs through discussion with their fellow students. However, the teacher often mediates classroom discussion (Cazden & Beck, 2003), serving as the mediator for classroom discussion rather than as an equal participant in the discussion with the students. The SPICE curriculum is an opportunity for students to engage in an integrated STEM project while also engaging in the practices of science through science talk and classroom discussion. With this research study, I aim to develop a greater understanding of the types and purposes of teacher questions and student responses within the context of the SPICE curriculum and provide recommendations to the district and to the SPICE curriculum regarding teacher questions and elicited student responses. Therefore, the following research question and sub-questions are addressed as part of this research study:

(1) What kinds of teacher questioning and opportunities for student response are present in the discussions during the enactment of the SPICE curriculum?

    a. In whole-class discussions, what is the frequency of teacher questioning as compared to student response?

    b. In whole-class discussions, to what extent do frequency and kind of teacher questioning as compared to student response differ by lesson?

    c. In whole-class discussions, what kinds of questions do teachers ask, and what kinds of student responses do these questions elicit?

In this chapter, I discuss the findings from this capstone study as organized around the research questions. Specifically, four themes emerge in the whole-class discussions: (1) teacher talk and closed-ended questions are predominant in the whole-class discussions; (2) the teacher mediates most of the student talk during the whole-class discussion; (3) teacher talk (i.e., closed-ended, or closed, and open-ended, or open) tends to elicit aligned student talk, with the predominance of closed question-narrow response pairs; and (4) different types of question sequences are associated with different proportions of open and closed teacher talk depending on the purpose of the question sequence.

Theme 1: The Predominance of Teacher Talk and Closed Questions

Teacher talk, teacher questions, and student responses are chosen as a focus for this research study because teacher talk, especially teacher questioning, provides an opportunity and serves as a model for students' engagement in classroom discussion. The amount that teachers speak in whole-class discussions and the types of questions that teachers ask are both related to the amount of students' participation in whole-class discussion. Data analysis suggests the predominance of teacher talk in which the teachers participate in the whole-class discussions more than the students in terms of sentences spoken and turns of talk. Data analysis also suggests the predominance of closed questions during the whole-class discussions.

Discussion-related and non-discussion-related classroom talk. It is important to understand the different kinds of classroom talk that the teachers and students engage in during the lessons. The two main groups of speakers who participate in the whole-class classroom talk are the teachers (i.e., Ms. Fisi, Mr. Quim) and the students. Both groups of speakers participate in the non-discussion-related and the discussion-related classroom talk in the SPICE curriculum. The discussion-related classroom talk contributes to the classroom discussions and includes teacher questions, teacher talk moves, and student responses that connect to the classroom discussion as part of the SPICE curriculum's science-focused lessons. The non-discussion-related classroom talk does not contribute to classroom discussions and generally includes teacher talk and student talk that connect to logistics, activity procedures, or content instruction. The discussion-related classroom talk introduces and maintains classroom discussions while the non-discussion-related classroom talk is separate from the classroom discussions.

Example of discussion-related talk. The following excerpt from Day 4 of the morning section provides an example of teachers and students engaging in discussion-related talk surrounding an instance of non-discussion-related talk:

Ms. Fisi: So both videos showed rain, correct?	Discussion-related
Students: Yeah	Discussion-related
Ms. Fisi: I need all computers at a 45-degree angle in	Non-discussion-related

the next three… two… one. Thank you, [Student], yours is perfect, it’s not closed, but it’s also not at a 90-degree angle.	
Ms. Fisi: So what was the difference between the two videos? Who can tell me? What did you notice? [Student]?	Discussion-related
Student 1: The one on the left was heavy rain and-	Discussion-related
Ms. Fisi: Yeah, the one on the left was really heavy.	Discussion-related
Student 1: And it appeared to be raining faster.	Discussion-related
Ms. Fisi: Okay, and it appeared to be raining faster. [Student]?	Discussion-related
Student 2: The heavy rainfall looked like it was flooding and it was really fast and then the light rainfall was like water dripping out of a faucet and it was really slow and it wasn’t flowing as much.	Discussion-related
Ms. Fisi: Okay, and I see a couple of people agree with you on that.	Discussion-related
(Lesson 3, Morning, February 1, 2019)	

This excerpt demonstrates the difference between discussion-related talk and non-discussion-related talk. Ms. Fisi begins the discussion with a question, and the student responds. After this initial exchange, Ms. Fisi addresses the students with non-discussion-related talk, specifically addressing classroom management. Ms. Fisi then returns to the classroom discussion with two questions about the differences between the two videos and two requests for students to participate in the discussion. The students then respond to the question about the videos, and Ms. Fisi maintains the classroom discussion by restating Student 1’s responses, nominating Student 2 to add to the discussion, and acknowledging the other students’ agreement with Student 2’s response.

This excerpt demonstrates that the discussion-related classroom talk typically begins with teacher questions, and the teachers maintain these discussions with various teacher talk moves, such as asking follow-up questions, providing feedback to students about their responses, restating responses, and nominating students to contribute to the discussion. At times, the teachers pause the discussions to address the students with non-discussion-related talk. During the discussions, students respond to the teachers' questions but sometimes also respond to other students' contributions to the discussions. Most of this chapter focuses on discussion-related talk and the different ways that teachers and students contribute to the classroom discussions.

Examples of non-discussion-related talk. As described in the previous excerpt, the teachers engage in the classroom talk through discussion-related and non-discussion-related talk. Non-discussion-related talk includes teacher and student talk that do not promote or support classroom discussion. In the previous excerpt, the non-discussion-related talk is an example of logistics talk that addresses classroom management. Table 4.1 depicts the three categories of non-discussion-related talk and examples of each category: logistics talk, including giving directions, classroom management, and gaining students' attention; activity procedure talk; and content instruction, including telling information and call-and-response exercises. The examples of gaining students' attention under logistics talk and the call-and-response exercise under content instruction are included to demonstrate that not all teachers' requests for students to contribute to the classroom talk and not all student responses are related to discussion. The teachers institute call-and-response norms to reinforce a concept, to demonstrate a pronunciation, or to emphasize an aspect of a procedure. However, while these exchanges involve both teacher and student talk and are important for the flow of the lesson outside of classroom discussion, they do not promote or support discussion, so these examples of teacher talk and student talk are not explored in detail in this chapter.

Table 4.1
Examples of non-discussion-related talk

Non-Discussion-Related Talk	Example(s) from Transcripts
Logistics	Providing directions **Ms. Fisi:** "All right, I want you to take 10 seconds." (Lesson 2, Afternoon, January 29, 2019) Classroom management **Ms. Fisi:** "Even if you have a little bit of an idea, I want you to raise your hand." (Lesson 2, Afternoon, January 29, 2019) Gaining students' attention **Mr. Quim:** "Class, class." **Students:** "Yes, yes." (Lesson 3, Afternoon, January 30, 2019)
Activity procedures	Providing directions about the activity **Mr. Quim:** "If you're going, if you're done with questions one and two, move on to questions three and four if you'd like. You're welcome to have a look at your supplies there, next to your table. So when they say what supplies represent, they're right next to your table. Try to remember from yesterday what they were representing." (Lesson 3, Morning, January 31, 2019)
Content instruction	Telling information (e.g., about content, design decisions) **Ms. Fisi:** "This is very similar to the skill that we just practiced. Adding and subtracting fractions. 100 hundredths minus 15 hundredths gives us 85 hundredths. That's all. That's how you figure out what absorbed and what stays on top." (Lesson 4, Morning, February 11, 2019) Call and response (e.g., mirror exercises) **Ms. Fisi:** "Everybody say, 'One minute.' " **Students:** "One minute." (Lesson 4, Afternoon, February 6, 2019)

More discussion-related talk than non-discussion-related talk. Although the teachers and students engage in both discussion-related talk and non-discussion-related talk, there is more discussion-related talk than non-discussion-related talk aggregated

Table 4.2
Summary of discussion-related and non-discussion-related talk by sentence

Type of Talk	Number of Sentences	Percentage of Total Sentences
Total sentences	7613	
Non-discussion-related	2738	36.0%
Logistics	1566	20.6%
Activity procedures	888	11.7%
Content instruction	284	3.7%
Discussion-related talk	4875	64.0%
Teacher question/talk move	3802	49.9%
Student talk	1073	14.1%

across all of the science-focused lessons in both the morning and afternoon sessions. Table 4.2 depicts a summary of the frequency counts and the percentages of the discussion-related and non-discussion-related talk by sentence out of the total number of sentences spoken during the lessons and aggregated across the morning and afternoon sections. This chapter focuses on teacher and student turns of talk so that the number of sentences spoken by the teachers is not overemphasized, and this table is included to demonstrate the relative abundance of discussion-related talk and non-discussion-related talk and of teacher talk and student talk.

As depicted in Table 4.2, there is more discussion-related talk than non-discussion-related talk. Nearly two-thirds (64.0%) of the sentences spoken is related to discussion whereas slightly more than one-third (36.0%) of the sentences is not related to discussion. Most non-discussion-related talk is characterized as logistics talk (20.6%), such as classroom management. In terms of discussion-related talk, the teachers speak a much higher proportion of sentences (49.9%) compared to the students (14.1%). In fact, nearly half (49.9%) of all the sentences spoken during the lessons, across discussion-related and non-discussion-related talk, is characterized as discussion-related teacher talk, such as a teacher question or talk move. This difference suggests that the teachers mediate a high proportion of the whole-class discussions. In terms of sentences spoken, most classroom talk is discussion-related, and the teachers speak three to four times as many sentences as the students during the whole-class discussions.

Sentence-level observations versus turns of talk. As depicted in Table 4.2, most of the sentences spoken are related to classroom discussion, and the teachers speak most of these discussion-related sentences. While looking at number of sentences provides information about the amount that teachers and students speak during the whole-class discussions, the number of sentences spoken by teachers compared to sentences spoken by students may mislead. For example, in the below excerpt, when Ms. Fisi asks the students about the differences between two videos, she uses four sentences or phrases whereas the student responds in one phrase:

> **Ms. Fisi:** So what was the difference between the two videos? Who can tell me? What did you notice? [Student]?
> **Student 1:** The one on the left was heavy rain and-
> (Lesson 3, Morning, February 1, 2019)

In this case, the number of sentences overemphasizes Ms. Fisi's contribution to the discussion. Two questions center on the students' observations, and two other questions ask students to participate in the discussion, but the four sentences serve a single purpose of asking the students to describe their observations. The student responds to Ms. Fisi's questions with a single sentence. The four sentences of teacher talk serve one purpose of eliciting one sentence of student talk, but comparing the number of sentences spoken suggests that the teacher speaks more in the whole-class discussion than students speak.

Therefore, examining the number of sentences overemphasizes the total amount of teachers' and students' classroom talk.

In contrast, examining the turns of talk can provide more information about the relationship between teacher talk and student talk, such as what kind of teacher talk elicits a certain kind of student talk, rather than examining the overall amount of talk. For example, in the above excerpt, Ms. Fisi's four questions are all asked in sequence, so the four sentences comprise a single turn of teacher talk, and Student 1's response is a separate turn of student talk. By examining turns of talk, Ms. Fisi does not ask three unanswered questions and one question that Student 1 answers; instead, all four questions serve one purpose, and Student 1's response addresses Ms. Fisi's questions. Therefore, examining turns of talk can provide greater detail about the relationship between teacher talk and student talk within the classroom discussion.

Even with greater detail through turns of talk, it is important to consider the number of sentences spoken by teachers and students since relative amounts of talk can affect the flow of the classroom discussion. Table 4.3 displays a summary of the average number of sentences per turn of talk for discussion-related and non-discussion-related talk. Like the classroom discussion in the above example, teachers generally use 3.7 sentences per turn of talk, and students generally use 1.0 sentence per turn of talk. In terms of non-discussion-related talk, teachers use 8.3 sentences per turn of talk. Table 4.2 includes examples of teachers using multiple sentences for a single turn of talk for non-discussion-related talk, particularly the examples for providing directions for activity procedures and telling information under content instruction. Therefore, the primary analysis for this chapter focuses on turns of talk rather than number of sentences.

Table 4.3
Summary of number of sentences per teacher and student turn of talk

Type of Talk	Number of Sentences	Number of Turns of Talk	Average Number of Sentences Per Turn of Talk
Total	7613	2388	3.2
Discussion-related teacher talk	3802	1026	3.7
Discussion-related student talk	1073	1033	1.0
Non-discussion-related	2738	331	8.3

As an additional note about the turns of talk, the teacher talk from Ms. Fisi, the classroom teacher, and Mr. Quim, the STEM specialist, are considered the same. Both teachers are equal co-teachers and often alternate teaching lessons or interject while the other teacher speaks. For example, in the following excerpt, Mr. Quim responds to a student's response, and then Ms. Fisi also provides feedback to the student:

> **Mr. Quim:** That's actually what we do with the 3D printer, yeah, we make models of little things. Absolutely. And, yes, in some classes we do, right? So we might be able to make predictions with models.
> **Ms. Fisi:** And that's a really good point, because we're talking about runoff, right?
> (Lesson 2, Morning, January 29, 2019)

In the above excerpt, the teacher talk has two speakers but functions as one turn of talk. Typically, a change in speaker from teacher to student or student to teacher represents a change in turn of talk. In addition to examining the differences between the proportions of the number of sentences of discussion-related and non-discussion-related talk, the differences between the kinds of discussion-related teacher talk are also examined.

Teacher questions and talk moves. Within turns of talk, the discussion-related teacher talk is further categorized as teacher questions and teacher talk moves. The teacher questions are characterized as open questions or as closed questions and introduce

Table 4.4
Summary of teacher talk and student talk, by turns of talk

Type of Talk	Number of Turns of Talk	Percentage of Total Turns of Talk
Total turns of talk	2388	
Non-discussion-related	337	14.1%
Discussion-related teacher talk	1019	42.7%
Teacher questions	701	29.4%
Open	263	11.0%
Closed	438	18.3%
Teacher talk moves	318	13.3%
Following-up	129	5.4%
Pressing	36	1.5%
Restating	63	2.6%
Nominating	90	3.8%
Student talk	1032	43.2%
Mediated by teacher talk	991	41.5%
Not mediated by teacher talk	41	1.7%

question sequences in the classroom discussions or maintain student participation in the classroom discussions through follow-up questions. The teachers use talk moves to support and maintain student participation in the classroom discussions. While other talk moves are present during the lessons, the talk moves that most relate to student talk include following-up, pressing, restating, and nominating. The teachers generally use both teacher questions and talk moves in classroom discussions. The different kinds of teacher talk and their relationship to each other are described in this section.

Greater proportion of teacher questions than talk moves. As described above, the discussion-related teacher talk includes questions and talk moves. Table 4.4 displays a summary of the proportions of the different turns of talk for the teachers (i.e., questions, talk moves) and for the students out of the total turns of talk. Like the findings displayed in Table 4.2, there is a greater proportion of discussion-related turns of talk (85.9%, calculated by combining the proportions of teacher and student turns of talk) than non-discussion-related turns of talk (14.1%). There are also similar proportions of teacher turns of talk (42.7%) as student turns of talk (43.2%). However, within the category of teacher turns of talk, there is a greater proportion of teacher questions (29.4%) than teacher talk moves (13.3%). This difference suggests that the teachers employ various methods to engage the students in the classroom discussion but also that the teachers ask questions more frequently than they utilize talk moves to support students' responses during classroom discussions. The differences between the teacher questions and the teacher talk moves are described in more detail below.

Closed and open teacher questions. The teacher questions generally encourage students to engage in the classroom discussions. Through participation in the discussions, the teachers provide the students with opportunities to engage in the science practices, especially science talk. The questions typically occur in a sequence of questions that center around a single concept. For example, in the following excerpt, the teacher questions center on different surface materials and their effects on rainwater absorption and drainage. Specifically, in this excerpt, the teachers use questions to discuss the students' claims as the students develop an argument about the amount of absorption and its relationship to the amount of total rainfall and the type of surface material:

Ms. Fisi: Okay, so our question, "How do different surfaces affect where water goes?" So, what are your claims? Your claim is essentially your answer to that question, what you think. What are your claims? [Student].	Open question- Ideas

Student 1: I think some surfaces absorb more water but not most.	Broad response- Ideas
Ms. Fisi: Does anyone else want to share out?	Closed question- Yes/no
Ms. Fisi: So, [Student], when we're talking about the ability to absorb. Is there an official name for that?	Closed question- Factual recall
Student 2: Permeable?	Narrow response- Factual recall
Ms. Fisi: Okay, absolutely. So permeability. Okay.	Talk move- Restating
(Lesson 4, Afternoon, February 8, 2019)	

This excerpt serves as an example of question exchanges between the teachers and the students. In this excerpt, Ms. Fisi asks the students for their argumentation claims with an open question, or a type of question that elicit multiple student responses that are not necessarily correct or incorrect. While the SPICE curriculum specifies three different claims that students are expected to generate, the teacher does not specify any constraints or expect the students to provide a particular answer in this case. After one student response, the teacher continues by asking two closed questions, or questions that elicit a particular student response that is generally considered correct or incorrect. Ms. Fisi asks for more student responses to the discussion about claims and then asks to name a particular vocabulary term that matches a specific definition. To end the question sequence about the absorption of different surface materials, Ms. Fisi restates the student's vocabulary response and evaluates it as correct. This exchange centers on the amount of rainfall absorption of different surface materials and demonstrates the differences between open and closed teacher questions. Despite the differences, the teachers use the two types of questions complementarily. In this excerpt, the teacher uses the open question to elicit a response from a student, and then the teacher builds on that response by asking another student for an appropriate scientific term to be used as part of the initial student's claim. Overall, teachers use both open and closed questions, whether separately or complementarily, to elicit student responses so that the students can construct understandings while engaging in the practice of science talk.

Although the teachers use both open and closed questions to elicit student responses, they do not use the same proportion of open and closed questions turns of talk in the science-focused lessons. As depicted in Table 4.4, the teacher questions comprise 29.4% of the turns of talk. However, the teachers ask more closed questions (18.3%) than open questions (11.0%). This difference suggests that the teachers tend to ask questions that elicit a correct response (i.e., closed questions) more frequently than questions that elicit responses without a single, correct response (i.e., open questions). Closed questions tend to elicit less student participation in the classroom discussions than open questions.

Teacher talk moves. Like teacher questions, teacher talk moves encourage students to participate in the classroom discussion. While teachers use questions to begin an exchange or to shift a discussion's focus to a different concept, teachers use talk moves to maintain or support a classroom discussion. Talk moves follow students' responses to questions. Teachers use talk moves to shift a discussion to a slightly different but still relevant concept, to ask a student to clarify a response, to delve more deeply into a concept, or to ask a student to participate in the classroom discussion. During the science-focused lessons, the talk moves that most relate to student responses include following-up, pressing, restating, and nominating talk moves.

Following-up. When teachers follow up with students' responses, they ask questions that center on a student's idea. These questions help a student generate a response by providing scaffolded support or clarify a student's response. For example, in the following excerpt from Lesson 3.2, the teacher asks questions in preparation for an investigation activity that explores how the rainfall duration affects the amount of total rainfall. The teacher questions center on the available materials for the investigation activity and the uses of the different materials:

Mr. Quim: Remember that the question is, “How does the amount of time that passes affect the total amount of rainfall?” So, tell me, really quickly, what do those cup things represent? What are they supposed to represent for us? Yeah.	Closed question- Activity set-up
Student 1: Rain	Narrow response- Activity set-up
Mr. Quim: What about the rain?	Talk move- Following-up
Student 1: How fast it goes down.	Narrow response- Activity set-up
Mr. Quim: How fast it goes down, okay.	Talk move- Restating
Mr. Quim: So, how fast or how slow it goes down. Like hourly rainfall. So you’ve got a low one and a high one, right.	Providing contextual information
Mr. Quim: Okay	Non-discussion-related- Logistics
Mr. Quim: What do you think that little container represents underneath? Yes.	Closed question- Activity set-up
Student 2: A rain gauge.	Narrow response- Activity set-up
Mr. Quim: It’s a rain gauge.	Talk move- Restating
Mr. Quim: Why do we have a timer? Yeah.	Closed question- Activity set-up
Student 3: To stop it.	Narrow response- Activity set-up
Mr. Quim: To stop what?	Talk move- Following-up
Student 3: The water.	Narrow response- Activity set-up
Mr. Quim: Why is there a timer or stopwatch? Yeah.	Talk move- Following-up
Student 4: To time how long the rain is falling.	Narrow response- Activity set-up
Mr. Quim: So, to time how long the rain is falling.	Talk move- Restating

(Lesson 3, Morning, January 30, 2019)

In this excerpt, Mr. Quim follows up with the students’ responses multiple times. In these instances, Mr. Quim uses following-up talk moves to ask the students to clarify their responses about the activity set-up and to scaffold the students’ understanding of the activity. In the first instance, Mr. Quim follows up with the student to clarify that the cups of water represent the rainfall intensity. In the second instance, Mr. Quim follows up with the students to scaffold their understanding that the timer represents the duration of the rainfall. When used in conjunction with closed questions, the following-up talk moves clarify students' responses and scaffold students' conceptual understanding.

In the previous excerpt, the following-up talk moves supports the closed questions that focus on the activity set-up for the investigation. The teachers also uses the following-up talk moves with open questions, such as when the students describe patterns that they observe in the data as depicted in the following excerpt:

Mr. Quim: What are we seeing here? Anybody notice a pattern so far?	Open question- Ideas
Student 1: Maybe the numbers are bigger.	Broad response- Ideas
Mr. Quim: What numbers are bigger?	Talk move- Following-up
Student 1: The, um, amount of water.	Broad response- Ideas
Mr. Quim: So the amount of water is getting bigger, and what's happening to the time?	Talk move- Following-up
Student 1: Time is also extending.	Broad response- Ideas
Mr. Quim: Extending. What's another word that we can use?	Talk move- Following-up
Student 1: Expanding.	Broad response- Ideas
Mr. Quim: Expanding. Time is expanding, and the amount of water is doing what?	Talk move- Following-up
Student 1: Growing.	Broad response- Ideas
Mr. Quim: Growing. Ok, good.	Talk move- Restating

(Lesson 3, Afternoon, January 31, 2019)

In this exchange, the open question initiates a discussion about observing patterns in the data. With each student response, Mr. Quim follows up with the student, using the student's words to support the student's understanding. Over the course of four following-up talk moves, the teacher guides the student to connect increased rainfall duration with increased amount of rainfall. The following-up talk moves clarify students' responses, provide additional information for the discussion, and scaffold students' thinking to make connections among concepts.

Pressing. Similar to following-up talk moves, pressing talk moves ask students to elaborate on their responses. The teachers ask students to speak more deeply about an idea, add to an explanation, provide further evidence to support a claim, or present ideas, observations, or personal experiences relevant to the discussion. Pressing talk moves generally include "Why?" or "How?" questions. In the following example, the teacher presses students to further develop their reasoning to support their scientific claim (i.e., total rainfall equals the product of hourly rainfall and duration) with evidence. This excerpt begins part of the way through the discussion on argumentation reasoning:

Mr. Quim: Ok, so I heard "amount of time." What word could we use to kind of substitute that?	Closed question- Factual recall
Student 1: Duration.	Narrow response- Factual recall
Mr. Quim: Ok, so think about duration. And then what else might help us out? And you said something about total amount of water, too, right? Ok, keep going. So duration and total amount of water. What else? What else do we know based on our evidence?	Talk move- Pressing
Student 1: That it depends on the water.	Broad response- Explanation
Mr. Quim: What is, what is "it" that depends?	Talk move- Pressing
Student 1: That it, that it, that they, um, amount of water has, um, how big the rainfall is.	Broad response- Explanation
Mr. Quim: How big the rainfall is?	Talk move- Pressing
Student 1: Like, how, like, strong or, like, how much rain's coming down.	Broad response- Explanation
(Lesson 3, Afternoon, February 5, 2019)	

This exchange begins with a factual recall closed question asking about correct terminology. Mr. Quim then presses the student multiple times to further explain the claim that rainfall intensity and rainfall duration determine total rainfall and to elaborate on the supporting evidence. With these pressing talk moves, the teachers ask the students to elaborate on ideas and explanations and to add observations and personal experiences to the classroom discussion.

Restating. The teachers employ the restating talk moves to repeat the student talk or to ask the students to clarify their responses. In the following example, the closed teacher question asks the students about calculating amount of total rainfall from hourly rainfall rate and duration of rainfall:

Ms. Fisi: So [Student] said to get the total amount of rain you have to multiply. And what did we multiply? She said to multiply by what?	Closed question- Factual recall
Student 1: Hourly rainfall.	Narrow response- Factual recall
Ms. Fisi: Hourly rainfall.	Talk move- Restating
(Lesson 3, Morning, February 6, 2019)	

In this excerpt, Ms. Fisi restates the student's response. This example demonstrates a common pattern of teacher talk followed by student response and restating the response. Sometimes, this restating emphasizes the response for further discussion or for use as an exemplar of student response. However, the classroom discussions during the science-focused lessons occur in a large room where teachers and students sometimes have difficulty hearing each other. Therefore, the restating talk moves sometimes highlight a student's response and other times serve to repeat the response to verify the student's response or to ensure that all students hear the response.

To verify a student's response, the teachers restate the response and then ask the student for verification. In the following example, the exchange focuses on preparing for an investigation of absorption and runoff that depends on changing the angle of the slope:

Mr. Quim: At the very top there is a scientific question. Your first question, what question are we answering? Can somebody read for us- what question are we trying to answer in this experiment that we're going to do right now? Yeah.	Closed question- Factual recall
Student 1: Which slope will cause the most, and least, water to run off?	Narrow response- Factual recall
Mr. Quim: Which slope will cause the most water and the least water to run off, is that what it says?	Talk move- Restating
Student 1: The most and least water to run off- isn't the high slope the most?	Narrow response- Factual recall

(Lesson 5, Morning, February 13, 2019)

In this excerpt, Mr. Quim restates the student's response and asks for verification. Other times, the teachers ask the students to restate their responses because of the difficulty hearing responses in the classroom. In the following example, the teachers and students develop a claim that connects the different surface materials and the amount of runoff:

Ms. Fisi: What else? Any other claims?	Open question- Ideas
Student 1: I think that more absorbent or…	Broad response- Ideas
Ms. Fisi: The more… say that one more time nice and loud.	Talk move- Restating
Student 1: The more absorbent or permeable a surface is, the less water will flow off it.	Broad response- Ideas

(Lesson 4, Afternoon, February 8, 2019)

In this excerpt, Ms. Fisi ask the student to restate the response so that the entire class hears it. Therefore, the restating talk moves sometimes identifies model student responses but often addresses the practical challenges of working in a large classroom that made classroom discussions difficult to hear.

Nominating. In contrast to the other talk moves, the nominating talk moves manage student participation in the classroom discussion. The teachers nominate students to participate by saying their names or by using a generic word such as "Yes" or "Yeah" to call on students. These nominating actions sometimes occur at the end of a question turn of talk. In the following example, Mr. Quim asks a series of closed questions and then nominates a student to respond, but in instances like this example the entire turn of talk is categorized as a closed question rather than as a nominating talk move:

Mr. Quim: Remember that the question is, "How does the amount of time that passes affect the total amount of rainfall?" So, tell me, really quickly, what do those cup things represent? What are they supposed to represent for us? Yeah. (Lesson 3, Morning, January 30, 2019)	Closed question- Activity set-up

Sometimes, the nominating talk moves occur independently of teacher questions or other talk moves, and this separation allows for multiple students to respond to the initial teacher question. In the following example, the students try to determine the amount of rainfall at BUES. The open question asks the students to consider the importance of interpreting multiple years of data rather than a single year of data:

Ms. Fisi: Why do we need to know how much rainfall happened six years ago?	Open question- Ideas
Student 1: So you can like use it <inaudible>, you know how much falls in a long time. If you only like do it for two days, it's, I don't know.	Broad response- Ideas
Ms. Fisi: But you're getting there, you're absolutely getting there. I can tell that you're on the right track. [Student], what'd you think?	Talk move- Nominating
Student 2: Um, cause say one day it might have rained like a lot, and then the next day it might not have rained that much, so you need to go as far back as possible, so like so that at the point where like we can see like all the times that it rained and stuff like that so <inaudible>, last year maybe it didn't rain that much or like, yeah.	Broad response- Ideas
Ms. Fisi: Okay, thank you. [Student].	Talk move- Nominating

Student 3: Maybe to see just how much rain increased or decreased? Broad response- Ideas
(Lesson 3, Afternoon, February 1, 2019)

Ms. Fisi begins with an initial open question and nominates multiple students to respond. Through multiple nominations, multiple students provide different ideas and explanations to a single question, which demonstrates to the students that some questions in science practice can generate multiple responses. The nominating talk moves manage students' contributions to the discussion, including multiple responses to individual questions.

Comparing teacher talk moves. The teacher talk moves examined in this chapter (i.e., following-up, pressing, restating, nominating) directly mediate or manage student responses. As depicted in Table 4.4, there is a greater proportion of following-up talk moves (5.4%) than nominating talk moves (3.8%), restating talk moves (2.6%), and pressing talk moves (1.5%). The following-up and pressing talk moves both ask students to elaborate further on their responses, and their combined proportions (6.9% of turns of talk) suggests that more than half of the talk moves ask students to elaborate on ideas, explanations, evidence, and experiences. Nominating talk moves are the second-highest proportion of talk moves. The following-up, pressing, and nominating talk moves comprise most of the talk moves, which suggests that, outside of open and closed questions, most instances of discussion-related teacher talk involve talk moves that ask for elaboration on a student response (i.e., following-up, pressing) or for multiple responses to a question (i.e., nominating). However, the low proportions of the talk moves suggest that teacher questions are more common than teacher talk moves.

Comparing teacher questions and teacher talk moves. As depicted in Table 4.4, teacher questions occur at a higher proportion of turns of talk (29.4%) than talk moves

(13.3%). The proportion of talk moves may be expected to be lower than the proportion of teacher questions. Based on the coding scheme, initial questions begin each question sequence before turns of talk are categorized as talk moves. However, if teachers use following-up or pressing talk moves to ask students to elaborate or use nominating talk moves to elicit multiple student responses to a single question, then the proportion of talk moves could be higher than the proportion of teacher questions. For example, in the second excerpt above for following-up and in the excerpt above for pressing, multiple talk moves mediate student responses to elaborate on a single question. In the second excerpt above for nominating, talk moves mediate multiple student responses to a single question. However, the teacher questions occur more frequently than talk moves with multiple, individual questions that relate to a single topic like the following example:

Mr. Quim: So, when it says how much total water when it rains, there are intense storms or really, really heavy storms. But there are opposite storms to that, too.	Providing background information
Mr. Quim: What kind of storms would be like the opposite of a heavy storm?	Closed question- Factual recall
Student 1: A light storm.	Narrow response- Factual recall
Mr. Quim: Did we have any of those recently? Was anybody alive yesterday? Did we have a heavy storm or a light storm yesterday?	Closed question- Factual recall
Student 2: A light storm.	Narrow response- Factual recall
Mr. Quim: A light storm. So what's the difference between a heavy storm and light storm?	Open question- Ideas
Student 3: A light storm has less rain and a heavy storm has more rain.	Broad response- Ideas

(Lesson 3, Morning, January 30, 2019)

In classroom discussions, the proportion of teacher questions is greater than the proportion of talk moves, which suggests that within a single question sequence, the teachers more often ask separate questions that relate to a single overall concept than they employ talk moves to elicit further elaboration on a concept or multiple responses to a single question. The teachers encourage student talk in the classroom discussions, but the student talk primarily consists of responses to separate teacher questions than student responses that build on preceding student responses as managed through talk moves.

Teacher talk in individual, science-focused lessons. Within the classroom discussions, the discussion-related teacher talk is characterized as teacher questions and teacher talk moves. Looking at the data aggregated across all four science-focused lessons presented in the previous section, there is a higher proportion of teacher questions than talk moves, and there is a higher proportion of closed questions than open questions. When considering the lessons individually, each lesson covers related content about water runoff and follows a similar structure that begins with discussions about the content and ends with discussions about the student-generated models. Chapter 3 includes detailed descriptions of the science-focused lessons (i.e., Lessons 2, 3, 4, 5). Based on the similar lesson structures, similar proportions and kinds of teacher questions and talk moves may be expected in classroom discussions in each lesson. The different kinds of teacher talk in each lesson are described in the remainder of this section.

As depicted in Table 4.5, the proportions of teacher talk are similar across all four science-focused lessons. The highest proportion of discussion-related teacher talk occurs in Lesson 2 (47.0% of turns of talk), and similar proportions of discussion-related teacher talk also occur in the other lessons (Lesson 3: 41.5%; Lesson 4: 44.8%; Lesson 5: 42.5%). There may have been a higher proportion of teacher talk in Lesson 2 due to the structure of the SPICE curriculum. Lesson 2 is the first science-focused lesson, but the

Table 4.5
Summary of teacher talk and student response in each lesson, by turns of talk

	Percentage of Total Turns of Talk by Lesson			
Type of Talk	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Total turns of talk	279	1047	669	393
Non-discussion-related	8.6%	16.6%	10.3%	14.5%
Teacher talk	47.0%	41.5%	44.8%	42.5%
Teacher questions	32.6%	27.4%	30.8%	29.8%
Open	14.0%	10.6%	11.1%	9.9%
Closed	18.6%	16.8%	19.7%	19.8%
Teacher talk moves	14.3%	14.0%	14.1%	12.7%
Following-up	5.0%	5.8%	6.1%	4.1%
Pressing	2.2%	0.9%	2.5%	1.0%
Restating	0.7%	3.6%	1.6%	3.3%
Nominating	6.5%	3.7%	3.7%	4.3%
Student responses	44.4%	41.9%	44.8%	43.0%
Mediated by teacher talk	43.4%	40.1%	43.3%	40.7%
Not mediated by teacher talk	1.1%	1.8%	1.5%	2.3%

teachers also spend part of Lesson 2 reviewing the curriculum's water runoff challenge. Lesson 2 also lasts one class meeting whereas the other three lessons last more than one class meeting each, providing more opportunities for student talk with investigation activities and the corresponding discussions.

Similarly, there is a lower proportion of non-discussion-related turns of talk during Lesson 2 (8.6%) than during the other lessons (Lesson 3: 16.6%; Lesson 4: 10.3%; Lesson 5: 14.5%). This lower proportion of non-discussion-related talk may relate to few opportunities for talk about the set-up of investigation activities during Lesson 2 because the investigation activities occur during Lessons 3, 4, and 5 after the teachers introduce and model the appropriate ways of conducting the investigations. Since Lesson 2 lasts only one class meeting, this lower proportion of non-discussion-related talk may also relate to fewer opportunities for students to speak with their small groups, which corresponds to fewer opportunities for teachers to engage in logistics talk about engaging with their small groups and returning to the whole-class discussion. Overall, the teachers engage in similar proportions of discussion-related and non-discussion-related teacher talk in each of the science-focused lessons.

Teacher questions. In addition to overall discussion-related teacher talk, the proportions of teacher questions and talk moves in each science-focused lesson are also explored. As depicted in Table 4.5, similar proportions of teacher questions and talk moves occur in the separate science-focused lessons. The proportion of teacher questions is higher in Lesson 2 (32.6%) than in the other lessons (Lesson 3: 27.4%; Lesson 4: 30.8%; Lesson 5: 29.8%). Like the difference in proportions of overall teacher talk in separate lessons described above, this higher proportion of teacher questions during Lesson 2 may correspond to the different structure of Lesson 2 compared to the other lessons. Lessons 3, 4, and 5 include investigation activities and models for students to generate, but Lesson 2 features content instruction, a review of the water runoff design challenge, and an introduction to the computer program that the students use to create their models. The teachers mediate the classroom discussion through teacher questions as they introduce these new parts of the curriculum so that the students might work more independently during the other science-focused lessons. Finally, Lesson 2 lasts only one class meeting, so the teachers may use more teacher questions due to time constraints.

Open and closed questions. As depicted in Table 4.5, a higher proportion of closed questions than open questions occurs in the individual science-focused lessons.

Also, considering the science-focused lessons separately in Table 4.5, there is a higher proportion of open questions during Lesson 2 (14.0%) than during the other lessons (Lesson 3: 10.6%; Lesson 4: 11.1%; Lesson 5: 9.9%). However, the proportions of closed questions are not as consistent. The lowest proportion of closed questions occurs with Lesson 3 (16.8%) compared with the other lessons (Lesson 2: 18.6%; Lesson 4: 19.7%; Lesson 5: 19.8%). This difference in proportion of closed and open questions may relate to lesson structure. In each lesson, the teachers ask closed questions to develop students' understanding of the computer program used to create the water runoff models in Lesson 2 or of appropriate set-up of the investigation activities (i.e., Lesson 3: hourly rainfall and duration; Lesson 4: surface materials and absorption; Lesson 5: water runoff and slope). In general, the proportion of closed questions in each lesson is greater than the proportion of open questions. This difference suggests that the teachers ask questions with limited responses more frequently than they ask questions with multiple possible responses.

Differences in proportions of open and closed questions. While each individual lesson includes a higher proportion of closed questions than open questions, there is also an interesting finding in terms of the difference between the proportions of closed questions and open questions in each lesson. As shown in Table 4.5, the most balanced lesson in terms of proportions of closed questions and open questions is Lesson 2, in which teachers ask 4.6% more closed questions than open questions. The other lessons each include larger differences in proportions of questions (Lesson 3: 6.2% more closed questions; Lesson 4: 8.6% more closed questions; Lesson 5: 9.9% more closed questions). The lesson structures provide information about the higher proportion of closed questions than open questions. The teachers typically use closed questions to review the previous day's content at the start of each class meeting and to check students' understanding. Lessons 3, 4, and 5 last multiple class meetings while Lesson 2 only lasts one class meeting, so Lessons 3, 4, and 5 include more opportunities to review with closed questions. However, since the structures of Lessons 3, 4, and 5 are similar (i.e., discussion about the content, investigation activity, students' model revisions, discussion on model revisions), it is not expected for the difference in the proportion of closed questions compared to open questions to become progressively larger from lesson to lesson. This increase may relate to the teachers' intention to shorten the lengths of lessons and in turn use more closed questions to finish the curriculum by the predetermined end date. Further examination of the transcripts may provide insight.

Talk moves. Like the similar proportions of teacher questions across each lesson, there are similar proportions of talk moves across each lesson. As depicted in Table 4.5, the proportion of teacher questions in each lesson (Lesson 2: 32.6%; Lesson 3: 27.4%; Lesson 4: 30.8%; Lesson 5: 29.8%) is higher than the proportion of talk moves (Lesson 2: 14.3%; Lesson 3: 14.0%; Lesson 4: 14.1%; Lesson 5: 12.7%). Similarly, just as there are higher proportions of discussion-related teacher talk and of teacher questions in Lesson 2, there is a slightly higher proportion of talk moves in Lesson 2 than the other three lessons. However, the proportion of talk moves in Lesson 2 (14.3%) is comparable to the proportions of talk moves in Lesson 3 (14.0%) and Lesson 4 (14.1%). The lowest proportion of talk moves occurs in Lesson 5 (12.7%).

When looking at the individual categories of talk moves, the following-up talk moves occur at the most consistent proportions across all four lessons (Lesson 2: 5.0%; Lesson 3: 5.8%; Lesson 4: 6.1%; Lesson 5: 4.1%). The pressing talk moves also occur at relatively consistent proportions across all four lessons (Lesson 2: 2.2%; Lesson 3: 0.9%; Lesson 4: 2.5%; Lesson 5: 1.0%). These consistent proportions for following-up and pressing talk moves suggest that the teachers consistently provide scaffolded support for students to construct understanding or ask the students to elaborate on their responses and provide further evidence in each lesson.

On the other hand, the restating and nominating talk moves occur at inconsistent proportions of turns of talk across all four lessons. The proportions of restating talk moves fluctuate from lesson to lesson (Lesson 2: 0.7%; Lesson 3: 3.6%; Lesson 4: 1.6%; Lesson 5: 3.3%). However, since the teachers sometimes use the restating talk move for practical considerations, these differences may be due to differences in the ability to hear in the classroom from one class meeting to another. In contrast, the proportion of nominating talk moves for Lesson 2 (6.5%) is greater than the proportions of nominating talk moves for the other lessons (Lesson 3: 3.7%; Lesson 4: 3.7%; Lesson 5: 4.3%). This difference suggests that the teachers elicit multiple responses to questions more frequently during Lesson 2 than during other lessons.

Overall, the proportions of teacher talk, including teacher questions and talk moves, are similar across the four lessons. When considered in aggregate or in separate lessons, the combined proportion of discussion-related and non-discussion-related teacher talk is greater than the proportion of student talk. Further, for the aggregated data and the individual lesson data, the proportion of teacher questions is greater than the proportion of talk moves, and the proportion of closed questions is greater than the proportion of open questions. These differences suggest that the teachers encourage student talk in the classroom discussions. However, the student talk primarily consists of correct or incorrect responses to closed questions rather than responses to open questions or responses that develop out of previous discussions and build on previous student responses through talk moves. In addition to examining the differences in teacher talk, the differences in student talk in aggregate and in each lesson are also examined.

Theme 2: The Predominance of Teacher-Mediated Student Talk

Within the classroom discussions, the discussion-related turns of talk include teacher talk and student talk. The student talk is characterized as teacher-mediated and non-teacher-mediated student talk. As described in this section, most student talk is mediated by teacher talk, whether in response to a teacher question or a teacher talk move. The student responses are characterized as narrow responses and broad responses. The narrow responses have limited response options in that a student is limited by a certain number of correct or incorrect options. Narrow responses generally include ideas that do not require support or detail, such as factual recall. Broad responses include multiple possible response options that are not necessarily considered correct or incorrect. The broad responses include opportunities to share information, ideas, evidence, and experiences rather than factual recall. Since the students only respond based on the kind of teacher question or talk move, the designations for broad and narrow responses are determined not only by the response but also by the question or talk move. In contrast, the non-teacher-mediated student talk includes instances when the student's participation in the classroom discussion is not directly mediated by teacher talk, such as responding to a fellow student. The different kinds of student talk are described in this section.

Teacher-mediated student talk in the aggregated data. During these science-focused lessons, most student talk relates to discussion-related teacher talk. As shown in

Table 4.4, the proportion of discussion-related student talk (43.2%) is similar to the proportion of discussion-related teacher talk (42.7%), suggesting that students generally respond to most or all teacher questions or talk moves. Other times, the teacher turn of talk ends a question sequence and does not require a student response. However, this difference in proportions of discussion-related student talk and teacher talk also suggests that student talk occurs in scenarios other than responses to questions and talk moves, and this small proportion of non-teacher-mediated student talk is discussed in a later section.

With the teacher-mediated student talk, the students' contributions to the classroom discussion flow through the teacher. A common example of the teacher-mediated student talk is a student's response to a teacher question. In the following excerpt, the teacher's questions mediate the students' responses:

Mr. Quim: Did we have any of those recently? Was anybody alive yesterday? Did we have a heavy storm or a light storm yesterday?	Closed question- Factual recall
Student 1: A light storm.	Narrow response- Factual recall
Mr. Quim: A light storm. So what's the difference between a heavy storm and light storm?	Open question- Ideas
Student 2: A light storm has less rain and a heavy storm has more rain.	Broad response- Ideas
(Lesson 3, Morning, January 30, 2019)	

After the first closed question, the student responds with a factual recall response about the previous day's rainfall. Mr. Quim then asks an open question about the difference between types of rainfall intensity, and another student describes the difference with a broad response. In this excerpt, teacher questions mediate the student talk because the student talk directly follows and responds to the teacher question and because the teacher speaks between the student responses.

As seen in the previous example, teacher questions mediate the discussion-related student talk. Teacher talk moves also mediate student talk, providing opportunities for students to elaborate on their responses or to provide multiple responses to a single teacher question while the teachers direct the flow of the student talk within the discussion, particularly through nominating talk moves. In the following example, the students respond to a teacher question about defining and describing a scientific model:

Ms. Fisi: Can I please have the following people share? [Name], can you go first?	Talk move- Nominating
Student 1: A model predicts things.	Broad response- Ideas
Ms. Fisi: Okay, so he said a model predicts what will happen. Okay, [Student].	Talk move- Nominating
Student 2: Um, something that shows labels and details for something that we're making.	Broad response- Ideas
Ms. Fisi: Okay, so something that shows labels and details for something that we're making, okay. [Student].	Talk move- Nominating
Student 3: Maybe a picture of something that could be…	Broad response- Ideas
Ms. Fisi: Say that again.	Talk move- Restating
Student 3: Maybe a picture or like something that it could be like a picture if you don't know what that is.	Broad response- Ideas
Ms. Fisi: Okay, so something that it could be. [Student]?	Talk move- Nominating
Student 4: A model proves something.	Broad response- Ideas
Ms. Fisi: It proves something, okay. Good ideas. [Student]?	Talk move- Nominating
Student 5: A model is like it represents something that is too small or too big to look into.	Broad response- Ideas
Ms. Fisi: Okay, [Name] said a model is something that is either too small or too big for us to explore. Very good. [Student]?	Talk move- Nominating
Student 6: A model shows something scientific.	Broad response- Ideas
Ms. Fisi: A model shows something scientific. Okay, good.	Talk move- Restating

(Lesson 2, Afternoon, January 29, 2019)

In this excerpt, in response to the initial question, six different students respond with various definitions of models. Before each student speaks, Ms. Fisi nominates that student, suggesting that Ms. Fisi mediates the flow of the discussion to include multiple students in the discussion. While one goal of scientific discussions may be for students to contribute at their own pace without the teacher's mediation, Ms. Fisi's mediation provides an example for the students on how to engage in scientific discussions with their fellow students but without direction from the teacher. However, during the SPICE curriculum, the teachers mediate most of the student talk.

Non-teacher-mediated student talk in the aggregated data. Since most student talk is mediated by teacher talk, non-teacher-mediated student talk is uncommon. Table 4.4 shows that the proportion of student talk that does not directly follow a teacher question or talk move (i.e., non-teacher-mediated student talk) is low (1.7%). While non-teacher-mediated student talk is rare, there are different opportunities for the students to contribute to the whole-class discussion without directly responding to a teacher question or talk move. As depicted in Table 4.6, the four different types of non-teacher-mediated student talk include providing additional responses to the teacher question, asking questions directed to the teacher, commenting to the teacher about the question or the content, and student talk directed to other students.

Additional responses to teacher question. As shown in Table 4.6, the kind of non-teacher-mediated student talk with the highest proportion of turns of talk (0.9%) is additional responses to the teacher question. Most discussion-related student talk involves a student's direct response to a teacher question, but sometimes a student responds to a teacher question without a direct verbal nomination from the teacher. While the students'

Table 4.6
Summary of categories and percentages of non-teacher-mediated student turns of talk

Type of Non-Teacher-Mediated Student Talk	Number of Turns of Talk	Percentage of Total Turns of Talk
Total turns of talk	2388	
Additional responses to teacher question	21	0.9%
Questions directed to teacher (e.g., clarifying questions)	5	0.2%
Comments (e.g., to teacher, about lesson)	9	0.4%
Responses to other students	6	0.3%

responses do not directly follow the teacher question, the students ultimately answer the teacher question, so the teacher question indirectly mediates the students' responses. In the following example, the teacher asks about representing rainfall on the model:

Ms. Fisi: So another thing to think about is the type of rain we were just experiencing ourselves, think to yourself would that rain be flowing to the ground or would that rain be more like this picture and kind of running across the pavement?	Closed question- Yes/no
Student 1: I don't think it really soaks through the pavement.	Narrow response- Yes/no
Student 2: Yeah, there was rain just on the ground.	Narrow response- Yes/no (Non-teacher-mediated)
(Lesson 2, Afternoon, January 29, 2019)	

In this excerpt, Ms. Fisi asks a closed question about the interaction between rain and the pavement. Student 1 provides a narrow response directly to Ms. Fisi's question, and then Student 2 affirms Student 1's response with an additional response to Ms. Fisi's question. While Student 2's response does not directly follow the question, it is an additional response to the teacher question and so is indirectly mediated by the teacher question.

Additionally, there is a limitation regarding this finding. Since only the transcript text is analyzed, the analysis only yields the times that the teachers use verbal cues to mediate student responses (e.g., teacher questions, nominating talk moves). Teachers also use non-verbal cues (e.g., pointing or nodding at students) to call on students. Therefore, if teachers use non-verbal cues during these lessons, it can be assumed that some responses that are classified as non-teacher-mediated student talk are in fact mediated by the teachers' actions even if they are not mediated by the teacher talk. If some responses are mediated by the teachers' non-verbal cues, then non-teacher-mediated student talk would occur at a lower proportion of the turns of talk.

Question directed to the teacher. As depicted in Table 4.6, questions that are directed to the teacher occur at the lowest proportion of non-teacher-mediated student talk (0.2%). These student questions do not necessarily relate to the teacher's line of questioning. Students typically interject into the discussion when they need clarification on a concept or procedure. For example, the following exchange is about the water runoff design challenge. Mr. Quim begins by providing background information on the range of permeability of the surface materials:

Mr. Quim: It absorbs just a little, right? So it's kind of on a scale. Right? Like permeable and impermeable, we're kind of figuring out where things fall on that scale.	Providing background information
Student 1: What's a scale?	Question (Non-teacher-mediated)
Mr. Quim: That's a good question, right? So if super permeable is on one side and impermeable is on the other, then maybe something's kind of in the middle, so like what would be in the middle here?	Open question- Ideas
Student 1: Artificial turf.	Broad response- Ideas
Mr. Quim: So artificial turf would be like halfway, right, compared to the other ones, the surfaces.	Talk move- Restating
(Lesson 4, Afternoon, February 7, 2019)	

Rather than continuing the discussion without knowing the definition of "scale," Student 1 asks for clarification. Mr. Quim explains the positions of different materials on the scale and asks a question to check the student's understanding. While the student question is not mediated by a teacher question or talk move, the student asks the question in response to a teacher statement. Therefore, like the additional responses to the teacher questions, these examples of non-teacher-mediated student talk center on teacher talk.

Comments. The third category of non-teacher-mediated student talk includes comments. The student comments refer to the lesson or the content of the discussion, and the students direct the comments sometimes to the teachers and other times to no one in particular. Like the other categories of non-teacher-mediated student talk, these comments comprise a low proportion (0.4%) of the turns of talk. Typically, these comments do not change the focus of the lesson and are not acknowledged by the teacher. However, they are considered discussion-related talk because they represent one form of student contribution to the classroom talk. In the following example, the teachers show the students two videos that depict different rainfall intensities:

Ms. Fisi: So, what we're going to do, we're going to show you two different videos of heavy hourly rainfall and then low hourly rainfall, um, just so you can kind of see the difference between the two.	Providing background information
Ms. Fisi: Sounds good?	Closed question- Yes/no
Student 1: Yeah, yes.	Narrow response- Yes/no
Ms. Fisi: So this is high hourly rainfall. Ok. And then you have low hourly rainfall.	Providing background information
Student 2: Oh wow.	Broad response- Description (Non-teacher-mediated)
Student 3: Big difference.	Broad response- Description (Non-teacher-mediated)

(Lesson 3, Afternoon, January 31, 2019)

After watching the videos, Students 2 and 3 express their reaction to the differences between the different rainfall intensities on the videos, but the students do not direct these comments to the teacher. Since the students' comments are in response to the videos and not to a teacher question, these observational comments are not indirectly mediated by teacher talk like the kinds of non-teacher-mediated student talk previously discussed.

Responses directed to other students. As depicted in Table 4.6 and like the other kinds of non-teacher-mediated student talk, the responses directed to other students occur at a low proportion of turns of talk (0.3%). During the science-focused lessons, the responses directed to other students typically occur after students participate in an activity, such as discussing observations and patterns in the data, completing calculations, and reviewing other students' models. In the following example, the teacher asks the students to calculate the amount of total rainfall based on hourly rainfall rate and rainfall duration to observe a pattern in the data, but the students disagree on the calculation:

Ms. Fisi: So after four hours, how much would I have?	Talk move- Following-up
Student 1: 12 inches.	Narrow response- Factual recall
Ms. Fisi: I heard 12 inches?	Talk move- Restating
Student 1: Yeah, 12.	Narrow response- Factual recall
Student 2: Zero point twelve.	Other- reply (Non-teacher-mediated)
Student 3: No, 1.2!	Other- reply (Non-teacher-mediated)
Ms. Fisi: 1.2.	Talk move- Restating
(Lesson 3, Afternoon, January 31, 2019)	

When disagreeing with Student 1's calculation, two students respond and correct the calculation with a direct response to Student 1. In this excerpt, the three students respond to Ms. Fisi's initial question, but when they disagree with each other, they direct their replies to other students rather than to the teacher. These responses to other students serve as examples of non-teacher-mediated student talk that involve students speaking directly to other students within the discussion. Although these instances of non-teacher-mediated student talk are not common in the whole-class discussion, their presence suggests that more opportunities are possible with the appropriate lesson structures if the curricular activities that tend to result in non-teacher-mediated student talk are explored.

Student talk in individual, science-focused lessons. For discussion-related student talk, there are similar proportions in the individual, science-focused lessons. As depicted in Table 4.5, the lowest proportion of student talk occurs in Lesson 3 (41.9%), but this proportion is similar to the proportions of student talk in the other lessons (Lesson 2: 44.4%; Lesson 4: 44.8%; Lesson 5: 43.0%). The consistent proportions of discussion-related student talk suggest that students participate in whole-class discussions at similar proportions in the individual lessons.

Teacher-mediated student talk. Like the turns of talk for overall student talk, the proportions of teacher-mediated student talk are similar for the four science-focused lessons. As shown in Table 4.5, while the proportions for each lesson are similar, the proportions of teacher-mediated student talk for Lesson 2 (43.4%) and Lesson 4 (43.3%) are higher than the proportions of teacher-mediated student talk for Lesson 3 (40.1%) and Lesson 5 (40.7%). These lower proportions of teacher-mediated student talk for Lesson 3 and Lesson 5 are consistent with lower proportions of teacher questions, teacher talk moves, and overall teacher talk for Lesson 3 and Lesson 5. This relationship suggests that lower proportions of teacher-mediated student talk are associated with lower proportions of teacher talk and that higher proportions of teacher-mediated student talk are associated with higher proportions of teacher talk.

Non-teacher-mediated student talk. Similar to the proportions of turns of talk for overall student talk and teacher-mediated student talk depicted in Table 4.5, the proportions of non-teacher-mediated student talk are similar across the science-focused lessons, with the proportions of non-teacher-mediated student talk lower for Lesson 2 (1.1%) and Lesson 4 (1.5%) than for Lesson 3 (1.8%) and Lesson 5 (2.3%). These higher proportions of non-teacher-mediated student talk for Lesson 3 and Lesson 5 are also consistent with lower proportions of teacher-mediated student talk, overall student talk, teacher questions, teacher talk moves, and overall teacher talk as described above. Further, the lowest proportion of non-teacher-mediated student talk occurs during Lesson 2, which suggests a potential difference in the content or lesson structure for Lesson 2 compared to the other lessons. For example, Lesson 2 only lasts one class meeting while the other lessons last for more than one class meeting apiece, providing the students with fewer opportunities to engage in discussion during Lesson 2. In addition, the students create their initial water runoff models during Lesson 2 but revise their models in subsequent lessons based on new content knowledge (e.g., intensity and duration of rainfall; water absorption of different surface materials; water runoff and different slopes). The students may be more comfortable speaking about their fellow students' models during the later lessons with this deeper understanding of water runoff and with more opportunities to engage with their revised models. Finally, more student talk might occur during the investigation activities that are present in Lessons 3, 4, and 5 but not present in Lesson 2. The instances of non-teacher-mediated student talk in the science-focused lessons and the associated curricular activities (e.g., discussing or comparing models; activity set-up) are depicted in Table 4.7 and explored below.

Table 4.7
Summary of categories and percentages of non-teacher-mediated student turns of talk, by lesson and curricular activity

	Percentage of Total Turns of Talk			
Non-Teacher-Mediated Student Talk Type	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Total turns of talk	279	1047	669	393
Additional responses to teacher question	1.1%	0.9%	0.6%	1.3%
Discussing/Comparing models	0.7%	0.2%	-	0.5%
Activity set-up	0.4%	0.5%	0.4%	0.5%
Constructing an argument	-	0.1%	-	-
Data and observations	-	-	-	0.3%
Personal experience	-	-	0.1%	-
Defining a term	-	0.1%	-	-
Questions directed to teacher (e.g., clarifying questions)	0.0%	0.1%	0.6%	0.0%
Discussing/Comparing models	-	-	0.1%	-
Activity set-up	-	-	0.1%	-
Constructing an argument	-	0.1%	0.3%	-
Data and observations	-	-	-	-
Personal experience	-	-	-	-
Defining a term	-	-	-	-
Comments (e.g., to teacher, about lesson)	0.0%	0.5%	0.1%	0.8%
Discussing/Comparing models	-	0.1%	-	-
Activity set-up	-	-	-	-
Constructing an argument	-	-	-	-
Data and observations	-	0.4%	0.1%	0.8%
Personal experience	-	-	-	-
Defining a term	-	-	-	-
Responses to other students	0.0%	0.4%	0.1%	0.3%
Discussing/Comparing models	-	-	-	-
Activity set-up	-	-	-	0.3%
Constructing an argument	-	0.1%	-	-
Data and observations	-	0.3%	0.1%	-
Personal experience	-	-	-	-
Defining a term	-	-	-	-

Lesson 2. During Lesson 2, the non-teacher-mediated student talk only includes additional responses to the teacher question. As shown in Table 4.7, the higher proportion (0.7%) of the additional responses to the teacher questions occurs during discussions about the water runoff models, such as the model layouts and the relationship between

surface materials and amount of water runoff. The lower proportion (0.4%) of these turns of talk occurs during activity set-up for an investigation about determining the amount of rainfall. These instances of non-teacher-mediated student talk center on activities (i.e., rainfall investigation, model development) in which the students prepare to engage.

Lesson 3. As shown in Table 4.7, the non-teacher-mediated student talk during Lesson 3 includes all four types of non-teacher-mediated student talk. Like the other lessons, additional responses to teacher questions (0.9%) comprise the highest proportion of non-teacher-mediated student talk, and most instances of additional responses occur during activity set-up for an investigation about hourly rainfall rate and rainfall duration. Further, the students engage in non-teacher-mediated comments (0.5%) and responses to other students (0.4%) at higher proportions than they ask questions directed to the teacher (0.1%). Most of the comments (0.4%) and responses to other students (0.3%) occur during whole-class discussions about data and observations, including observations about video descriptions of different rainfall intensities and data calculations involving average rainfall and amount of total rainfall. These instances of non-teacher-mediated student talk primarily relate to the different stages of investigation activities, including activity set-up and supplies, data observations, data calculations, and data analysis after completing the investigation. Therefore, like Lesson 2, the non-teacher-mediated student talk in Lesson 3 relates to activities in which the students engage.

Lesson 4. Like Lesson 3, the non-teacher-mediated student talk during Lesson 4 includes all four types of non-teacher-mediated student talk. As shown in Table 4.7, both additional responses to teacher questions (0.6%) and questions directed to the teacher (0.6%) comprise the highest proportions of turns of talk during Lesson 4. Most additional responses to teacher questions (0.4%) occur during activity set-up as the students prepare for an investigation of surface materials and amount of rainfall absorption. Most questions directed to the teacher occur during discussions about scientific argumentation (0.3%), specifically the connection between type of surface material and water runoff. Though uncommon, the comments (0.1%) and responses to other students (0.1%) both relate to observations and data analysis discussion of the type and permeability of different surface materials during an investigation activity. These instances of non-teacher-mediated student talk all center on the different stages of the Lesson 4 investigation activity, including activity set-up, observations, data analysis, making conclusions, and developing a scientific argument about the permeability of different surface materials. Therefore, like the previous lessons, the non-teacher-mediated student talk in Lesson 4 relates to activities in which the students engage.

Lesson 5. The non-teacher-mediated student talk in Lesson 5 is not as varied as in Lesson 3 or Lesson 4 with no instances of questions directed to the teacher. As shown in Table 4.7, additional responses to the teacher question comprise the highest proportion (1.3%) of non-teacher-mediated student talk during Lesson 5. These additional responses split relatively evenly among discussions of the investigation activity set-up (0.5%), of data and observations (0.3%), and of revisions to the student-generated models (0.5%). These additional responses all connect to the investigation activity that explores the calculation of the amount of water runoff from amount of total rainfall and amount of water absorption. Additionally, the non-teacher-mediated comments (0.8%) on data and observations and the student responses to other students (0.3%) on activity set-up also connect to the Lesson 5 investigation activity. These instances of non-teacher-mediated student talk all center on the different stages of the Lesson 5 investigation activity on water runoff, including activity set-up, data and observations, and discussions about student-generated models. Therefore, like the previous lessons, the non-teacher-mediated student talk in Lesson 5 relates to the activities in which the students engage.

Similarities in non-teacher-mediated student talk across lessons. As discussed in this section, the non-teacher-mediated student talk connects to the curricular activities of each lesson. The students engage in non-teacher-mediated student talk during discussions about investigation activity procedures and activity set-up, about data collection and observations, about disagreements regarding data analysis and calculations, about constructing arguments based on scientific explanations, about connections between personal experiences and scientific explanations, and about comparisons of the student-developed water runoff models. These instances of non-teacher-mediated student talk primarily relate to each lesson's investigation activity. When the students engage with an activity, they tend to contribute more frequently to the classroom discussion without mediation from teacher questions or talk moves.

Overall, the proportions of student talk are similar across the four lessons. When considered in aggregate or in individual lessons, the proportion of discussion-related student talk is similar to the proportion of discussion-related teacher talk, which suggests that students tend to respond to each of the teacher questions and talk moves within the whole-class discussion. This similarity in proportions suggests that teacher talk mediates most student talk. Though not common, there are also instances of non-teacher-mediated student talk in each lesson. Further, these instances of non-teacher-mediated student talk tend to connect to students' experiences with and participation in the curricular activities, including the investigation activities and the development of the water runoff model. In addition to exploring the overall classroom talk and the differences in teacher talk and student talk both in aggregate and within the context of the individual lessons of the SPICE curriculum, it is also important to consider the pairs of teacher talk and elicited student responses. The following section focuses on the discussion-related teacher talk and the corresponding student responses that are elicited.

Theme 3: Predominance of Closed Question-Narrow Response Pairs

In the previous sections, teacher talk and student talk are considered separately. In this section, the pairs of teacher talk and the elicited student responses are also explored. Data analysis suggests the theme of the predominance of closed question-narrow responses pairs in the whole-class discussion. Closed teacher questions tend to elicit narrow student responses, and open teacher questions tend to elicit broad student responses. Closed question-narrow response pairs occur more frequently than open question-broad response pairs. In addition, talk moves are more frequently paired with broad student responses than with narrow student responses. Narrow student responses include yes/no binary responses, factual recall, and previously established design decisions or activity set-up procedures. Narrow responses are associated with limited classroom discussion because they refer to comprehension and recall. Broad responses include ideas, predictions or hypotheses, descriptions, and explanations or reasonings. Broad responses are associated with extended classroom discussion because they refer to students' ideas and thought processes. Therefore, the predominance of closed question-narrow response pairs suggests limited opportunities for student participation in extended classroom discussion. In addition to narrow and broad responses, the students also respond to teacher talk with questions or with no response. The different pairs of teacher talk and elicited student responses are examined in this section.

In the previous sections, the analysis centers on turns of talk. Turns of talk are used instead of sentence-level data to describe the teacher talk and student talk in order not to over-emphasize the amount of teacher talk. As described in the previous findings, the teacher talk mediates most of the student talk since the student talk typically occurs in response to a teacher question or a talk move. In this section, these pairs of teacher question and elicited student response or pairs of teacher talk move and elicited student response are used to examine teacher talk and the corresponding elicited student talk.

Teacher questions and student responses. The proportions of the different types of questions and the elicited student responses are depicted in Table 4.8. Closed questions typically elicit narrow student responses, and open questions typically elicit broad student responses. Closed questions align with narrow responses because they focus on recall and involve limited response options. Open questions align with broad responses because they refer to students' thinking and involve multiple response options. The designations of "closed question-narrow response" and "open question-broad response" pairs represent these elicitations. As described in Table 4.8, there is a higher proportion of closed question-narrow response pairs (39.7% of pairs) than open question-broad response pairs (23.4% of pairs). This difference suggests that the discussion-related talk primarily consists of closed questions and the aligned narrow responses.

Closed questions and narrow student responses. The teachers' closed questions typically elicit narrow student responses. The closed question-narrow response pairs include discussion questions about yes/no binary choices, factual recall, or design

Table 4.8
Summary of pairs of teacher talk and student responses in science-focused lessons

Teacher Talk and Student Response Pair Types	Number of Pairs	Percentage of Pairs
Total number of pairs	1033	
Closed teacher question/Narrow student response	410	39.7%
Closed- yes/no	109	10.6%
Closed- factual recall	246	23.8%
Closed- design decision; activity set-up	55	5.3%
Open teacher question/Broad student response	242	23.4%
Open- ideas	162	15.7%
Open- prediction	5	0.5%
Open- description	54	5.2%
Open- explanation/reasoning	21	2.0%
Talk moves/Narrow student response	108	10.5%
Following-up	57	5.5%
Pressing	2	0.2%
Restating	28	2.7%
Nominating	21	2.0%
Talk moves/Broad student response	210	20.3%
Following-up	72	7.0%
Pressing	34	3.3%
Restating	35	3.4%
Nominating	69	6.7%
Mis-matched pairs	3	0.3%
Closed question/Broad response	3	0.3%
Open question/Narrow response	-	-
Teacher talk/Student question response	18	1.7%
Closed question	3	0.3%
Open question	1	0.1%
Following-up	3	0.3%
Pressing	-	-
Restating	1	0.1%
Nominating	10	1.0%
No student response	42	4.1%
Closed teacher question/No student response	22	2.1%
Open teacher question/No student response	20	1.9%

decisions and investigation activity set-up. As depicted in Table 4.8, the closed question-narrow response pairs comprise nearly two-fifths (39.7%) of the question-response pairs. The closed question-narrow response pairs are described in more detail below.

Closed questions- Yes/no. As shown in Table 4.8, the closed question-narrow response pairs that elicit binary yes/no responses occur at a relatively low proportion (10.6%) of question-response pairs. This category of question-response pair focuses on closed questions and binary yes/no responses. Teachers use these question-response pairs to review previously learned content at the beginning of a class meeting, to check for understanding, or to ask a question to set up a classroom discussion. The following excerpt demonstrates an example of this closed question-narrow response pair:

Ms. Fisi: So another thing to think about is the type of rain we were just experiencing ourselves, think to yourself would that rain be flowing to the ground or would that rain be more like this picture and kind of running across the pavement?	Closed question- Yes/no
Student 1: I don’t think it really soaks through the pavement.	Narrow response- Yes/no
(Lesson 2, Afternoon, January 29, 2019)	

In this example, Ms. Fisi asks the students to consider their previous experiences to choose between two options for the movement of the rainfall. The student chooses the option that the rain would remain on the pavement. While the exchange includes limited response options, it sets up additional discussions about connections between the content and the students’ personal experiences and about the development of the students’ water runoff models. Even though the closed question elicits an initial narrow response, the exchange establishes common personal experiences as a starting point for discussion.

Closed questions- Factual recall. As shown in Table 4.8, the closed question-narrow response pairs that elicit factual recall responses occur at a relatively high proportion of question-response pairs (23.8%). Teachers use these question-response pairs to review content from previous class meetings or to discuss new content, such as vocabulary terms. The following excerpt demonstrates an example of this closed question-narrow response pair:

Ms. Fisi: So what do you think impermeable is?	Closed question- Factual recall
Student 1: Not soaking in water.	Narrow response- Factual recall
Ms. Fisi: Not soaking in the water, right?	Talk move- Restating
(Lesson 4, Morning, February 12, 2019)	

In this example, after introducing the term "permeable," Ms. Fisi asks the students to define the term "impermeable" based on the definition of the previous term. The student responds, and Ms. Fisi restates the student's response and affirms it as a correct answer. Like other exchanges framed by closed questions, this example demonstrates that teachers use closed question-factual recall narrow response pairs to check students' understanding and to facilitate communication in classroom discussions by establishing common scientific terms that the teachers and students use. Therefore, the closed question-narrow response pairs serve an important role in discussions by checking students' baseline understanding of content and establishing common terminology.

Closed questions- Activity set-up/ Design decisions. As shown in Table 4.8, the closed question-narrow response pairs that elicit investigation activity set-up procedures or that elicit students' water runoff model design decisions occur at the lowest proportion of closed question-narrow response pairs (5.3%). As part of a previously designed curriculum, the investigation activity procedures limit the activity set-up options. For the water runoff models, the students make some design decisions as a group, but the project's design constraints limit design options. The following excerpt demonstrates an example of this closed question-narrow response pair:

Mr. Quim: What do you think that little container represents underneath? Yes.	Closed question- Activity set-up
Student 1: A rain gauge.	Narrow response- Activity set-up
(Lesson 3, Morning, January 30, 2019)	

This exchange is part of a discussion about the uses of available materials for the Lesson 3 investigation activity, which examines the relationship between rainfall duration and hourly rainfall rate. To ensure a safe laboratory experience, the teachers use closed question-narrow response pairs to review the uses of each material and instrument with the students, including the cups of water as hourly rainfall rate, the collection containers as rain gauges, and the times as rainfall duration. Checking the common usage of different materials and instruments ensures that students examine the same phenomenon, which facilitates the data analysis discussion after the investigation activity. Like other closed question-narrow response pairs, this example shows that closed question-narrow response pairs establish the students' baseline understanding of content and investigation activity procedures. Therefore, the teachers use the closed question-narrow response pairs to establish common student experiences with investigation activities and water runoff models to facilitate subsequent classroom discussions.

Closed questions and no response, mis-matched pairs, and question responses. In addition to the previously discussed closed question-narrow response pairs, the closed questions also elicit instances of no student response, mis-matched broad responses, and question responses. As displayed in Table 4.8, the proportion of closed question-no response pairs (2.1%) is small. The subsequent teacher responses to closed question-no response pairs are explored in more detail in a later section. As previously discussed, the narrow responses typically align with closed questions, but mis-matched pairs occur. There is a low proportion (0.3%) of closed question-broad response pairs (i.e., closed question elicits broad response). The following excerpt is an example of a closed teacher question that elicits a broad student response:

Ms. Fisi: Could we show an arrow going down into the ground?	Closed question- Yes/no
Student 1: You could also show an arrow going this way and that way.	Broad response- Ideas
Mr. Quim: You mean like this one?	Talk move- Following-up
Student 1: Yeah, but underground (Lesson 2, Morning, January 29, 2019)	Broad response- Ideas

This example is part of a discussion on using the computer program to create the water runoff models, specifically the positions of arrows to represent the movement of rainfall. Although Ms. Fisi asks a closed question expecting a binary yes/no response, the student instead responds with a broad response and suggests additional positions for the arrows. Mr. Quim follows up with the student, the student corrects Mr. Quim's reference, and then the classroom discussion continues. While these closed question-broad response pairs are uncommon, the student responses sometimes do not align with the expected student response based on the teacher question.

Finally, though uncommon, the teacher questions also elicit question responses from students. There is a low proportion (0.3%) of closed question-question response pairs. These question responses from students typically include clarifying questions and content-related questions. The following excerpt is an example of a content-related question that extends the current concept or connects to other concepts or content areas:

Mr. Quim: Okay, anyone want to talk to him about that? Yeah.	Closed question- Yes/no
Student 1: This is more of a question <inaudible>, why the heck is there a giant rain arrow on his model?	Question
Mr. Quim: Good question, I don't know. (Lesson 2, Afternoon, January 29, 2019)	Response to question

This exchange is part of a discussion on creating the water runoff models. After creating the models, the teacher projects different students' models for the students to observe, evaluate, and compare. When Mr. Quim asks for comments about a model, one student responds with a related question about the size of the rain arrow in the model. This question response from Student 1 represents another instance of a student engaging in science talk as a teacher-mediated comment which was directed to another student. These instances demonstrate that students can engage in science talk directly with other students in the appropriate context and with sufficient support. While these pairs of closed teacher questions and various student responses occur, the low frequency of these pairs suggests that closed teacher questions typically align with narrow student responses.

Open questions and broad student responses. The teachers' open questions typically elicit broad student responses. These open question-broad response pairs include discussion questions about eliciting students' ideas, making hypotheses and predictions, describing data or observations, and providing explanations or reasonings. As depicted in Table 4.8, the open question-broad response pairs comprise nearly one-fourth (23.4%) of the question-response pairs. The open question-broad response pairs are described in more detail below.

Open questions- Ideas. As depicted in Table 4.8, the open question-broad response pairs that elicit students' ideas occur at the highest proportion (15.7%) of the open question-broad response pairs. This category of question-response pair includes the elicitation of students' prior knowledge; patterns in the data; students' personal experiences that connect to the concepts of rainfall, absorption, and runoff; and evaluations of students' models. The following excerpt demonstrates an example of this open question-broad response pair:

Mr. Quim: So what does it, what makes, what makes a rainstorm heavy? What makes a heavy rainstorm? Yeah.	Open question- Ideas
Student 1: Um, if <inaudible> over a long period of time, then the clouds get rain, like don't immediately rain, they wait a while, then a lot of water collects, then it just rains really hard when that happens like with multiple clouds.	Broad response- Ideas

(Lesson 3, Afternoon, January 30, 2019)

In this excerpt, the classroom discussion centers on distinguishing between different intensities of rainfall. Mr. Quim begins by eliciting students' ideas about the observable characteristics of a "heavy rainstorm." The student's extended response characterizes a heavy rainstorm as including a large volume of rainfall at a high intensity. This open question elicits one student's ideas about a heavy rainstorm, but other responses could have referred to duration of rainfall, the size of raindrops, and other aspects of a rainstorm (e.g., lightning, thunder). This open question also sets up further discussion about the differences between heavy rainstorms and light rainstorms and about the connections among rainfall intensity, rainfall duration, amount of total rainfall, and amount of water runoff. These open questions elicit multiple possible broad responses from students and enable teachers to guide the discussion in various directions for students to make connections among multiple concepts.

Open questions- Prediction/Hypothesis. As shown in Table 4.8, the open question-broad response pairs that elicit predictions and hypotheses before or during an investigation activity occur at a very low proportion (0.5%) of question-response pairs. Making predictions based on their experiences in and out of the classroom helps students anticipate their observations during investigation activities. Since investigation activities do not occur during each class meeting, the low proportion of open question-broad response pairs for predictions seems reasonable. The following excerpt demonstrates an example of this open question-broad response pair:

Ms. Fisi: What do you guys think will happen, um, when the rainfall hits the concrete? [Student].	Open question- Prediction
Student 1: Um, I think when it hits the concrete, um, like the blacktop, for instance, it like since there's dents in the blacktop, um, it's, it's going to start to flood out the blacktop because the blacktop doesn't have anything to soak in and the grass like, um, soaks everything in and it takes in all of the water, but sometimes, um, like it gets too muddy and <inaudible>. (Lesson 4, Morning, February 8, 2019)	Broad response- Prediction

This classroom discussion centers on the preparation for the Lesson 4 investigation activity about the water absorption of different surface materials. Ms. Fisi asks the students to predict the interaction between the rainfall and the concrete surface material. Using previous personal experiences, the student predicts that the concrete does not absorb water like the parking lot asphalt ("blacktop"), leading to the surrounding grassy areas absorbing the water runoff. The students are then able to test their predictions during the investigation activity. Like other discussions initiated with open questions, this example shows that teachers use open question-prediction broad response pairs to activate students' prior knowledge and their personal experiences and to use these types of evidence to make predictions and hypotheses. Therefore, these open question-broad response pairs assist students in science talk discussions by asking students to make predictions based in evidence.

Open questions- Description. As shown in Table 4.8, the open question-broad response pairs that elicit descriptions occur at a low proportion (5.2%) of question-response pairs. Teachers use open question-broad response pairs to elicit descriptions and data observations and typically occur before, during, or after the investigation activities that explore hourly rainfall rate, water absorption, and water runoff. The investigation activities do not occur during each class meeting, so the low proportion of these open question-broad response pairs is reasonable. The following excerpt demonstrates an example of this open question-broad response pair:

Ms. Fisi: So it says, "What patterns do you notice in your data?" What do you notice happened in your data as you went from no slope to a high slope? What happened to the runoff? [Student].	Open question- Description
Student 1: There was more runoff when there was a slope.	Broad response- Description
(Lesson 5, Morning, February 14, 2019)	

In this example, the discussion centers on the investigation activity that explores the relationship between slope and water runoff. Ms. Fisi asks the students about patterns in their data observations. The student responds that a slope corresponds to greater water runoff. Like other exchanges framed by open questions, this example demonstrates that teachers use open question-broad response pairs to elicit students' descriptions, including experiences with investigation activities, data observations, and observed patterns in the data. Therefore, the open question-broad response pairs guide students in science talk discussions by focusing students on data observations and the use of evidence.

Open questions- Explanation/Reasoning. As shown in Table 4.8, the open question-broad response pairs that elicit explanations and reasonings occur at a low proportion of question-response pairs (2.0%). Teachers use these question-response pairs to guide students' construction of explanations to clarify an idea or justify a claim. The following excerpt demonstrate an example of this open question-broad response pair:

Ms. Fisi: So when we're talking about patterns you see, everyone should record right here, they notice that there was a higher runoff amount with a higher slope.	Providing background information
Mr. Quim: Can anybody think of maybe why that would be? Can you guys talk about that? You got a surface like this versus a surface like this?	Open question- Explanation
Student 1: Maybe because it's slanted and just like going down.	Broad responses- Explanation
(Lesson 5, Morning, February 14, 2019)	

In this example, the classroom discussion focuses on the relationship among slope, type of surface material, and water runoff. Ms. Fisi activates the students' prior knowledge of the investigation activity and the association between greater slope and greater water runoff. Mr. Quim continues the discussion to ask the students for an explanation of the pattern observed in the data. The student explains the larger amount of water runoff as a function of the slope and the direction of the flow of the water. The teachers continue the discussion by guiding the students to make connections to the speed of the water and the attraction of gravity down the slope. These open questions guide the students in science talk like constructing explanations but also provide the students with opportunities to evaluate and comment on the proposed explanations.

Open questions and no response, mis-matched pairs, and question responses. In addition to the previously discussed open question-broad response pairs, the open questions also elicit instances of no student response and questions. As displayed in Table 4.8, the proportion of open question-no response pairs is small (1.9%). The subsequent teacher responses to open question-no response pairs are explored in more detail in a later section. Further, open questions align with broad student responses. Although there are some instances of mis-matched closed question-broad response pairs, there are no instances of mis-matched pairs with open questions (i.e., open question elicits narrow response). In each case, the open question elicits a broad response.

Finally, though uncommon, the open teacher questions also elicit question responses from students. There is a low proportion (0.1%) of open question-question response pairs. The question responses typically include clarifying questions and content-related questions. The following excerpt is an example of a clarifying question in which the student asks the teacher to clarify or repeat a statement, question, term, or concept:

Ms. Fisi: Okay, [Student], did you have something that you wanted to add?	Open question- Ideas
Student 1: What, uh, what do you mean by an, uh, equation?	Question
Ms. Fisi: By what?	Talk move- Restating
Student 1: By an equation.	Question
Ms. Fisi: An equation, so blank plus blank equals blank. That would be an equation. (Lesson 5, Afternoon, February 13, 2019)	Response to question

This exchange is part of a classroom discussion on developing the claim for a scientific explanation in the form of an equation as described in the SPICE curriculum. Specifically, the claim describes the sum of the amount of water absorption and the amount of water runoff yielding the amount of total rainfall. In this example, Ms. Fisi elicits additional ideas from the students, and the student responds with a question to clarify the term “equation” in the scientific claim. By clarifying this term, the student can engage in the classroom discussion about the claim and the subsequent discussions about evidence and reasoning. While these pairs of open teacher questions and various student responses occur, the low frequency of these pairs suggests that open teacher questions typically align with broad student responses. In addition to asking questions, the teachers also use talk moves that elicit student responses to support and maintain student participation in the classroom discussion.

Talk moves and elicited student responses. Within the classroom discussions, the discussion-related teacher talk includes teacher questions and teacher talk moves. Teachers use the following-up, pressing, restating, and nominating talk moves to maintain and support the classroom discussion and to guide students to construct their understanding about a concept. Since the teachers use the talk moves in conjunction with closed questions and open questions, the talk moves elicit both narrow and broad student responses. However, talk moves elicit broad responses at a higher frequency than talk moves elicit narrow responses. As previously discussed, narrow responses tend to establish common terminology and experiences among the students that set up additional classroom discussion, and broad responses tend to relate to students’ elicited ideas, predictions, descriptions, and explanations that maintain extended classroom discussions and provide multiple students with opportunities to contribute to the classroom discussions. As depicted in Table 4.8, out of the teacher talk-student response pairs, there is a higher frequency of talk move-broad response pairs (20.3%) than talk move-narrow response pairs (10.5%). This difference suggests that teachers use talk moves to ask students to elaborate more on their broad responses than on their narrow responses. This difference also suggests that elicited broad student responses are more associated with maintaining and supporting classroom discussion than elicited narrow student responses. The talk moves and the elicited student responses are described in more detail below.

Following-up and elicited student responses. The teachers use the following-up talk moves to ask questions about a student's idea or to provide scaffolded support for a student in constructing an understanding. As depicted in Table 4.8, there is a higher but comparable proportion of following-up-broad response pairs (7.0%) than following-up-narrow response pairs (5.5%). This difference suggests that teachers use following-up talk moves at a slightly higher frequency in conjunction with open questions that elicit broad responses than with closed questions that elicit narrow responses. The first excerpt demonstrates an example of following-up-narrow response pairs:

Mr. Quim: Why do we have a timer? Yeah.	Closed question- Activity set-up
Student 1: To stop it.	Narrow response- Activity set-up
Mr. Quim: To stop what?	Talk move- Following-up
Student 1: The water.	Narrow response- Activity set-up
Mr. Quim: Why is there a timer or stopwatch? Yeah.	Talk move- Following-up
Student 2: To time how long the rain is falling.	Narrow response- Activity set-up
Mr. Quim: So, to time how long the rain is falling.	Talk move- Restating
(Lesson 3, Morning, January 30, 2019)	

In the first excerpt, Mr. Quim leads the discussion about the functions of the materials and instruments used for data collection during the investigation activity, which explores the relationship among rainfall duration, hourly rainfall rate, and amount of total rainfall. Mr. Quim uses multiple following-up talk moves to elicit from the student the correct use of the timer to determine rainfall duration. These following-up-narrow response pairs clarify the correct use of the instruments during the planned investigation activity. The second excerpt demonstrates an example of following-up-broad response pairs:

Mr. Quim: What are we seeing here? Anybody notice a pattern so far?	Open question- Ideas
Student 1: Maybe the numbers are bigger.	Broad response- Ideas
Mr. Quim: What numbers are bigger?	Talk move- Following-up
Student 1: The, um, amount of water.	Broad response- Ideas
Mr. Quim: So the amount of water is getting bigger, and what's happening to the time?	Talk move- Following-up
Student 1: Time is also extending. (Lesson 3, Afternoon, January 31, 2019)	Broad response- Ideas

In this example, Mr. Quim leads the classroom discussion on patterns in the data, specifically the relationship between increasing duration and increasing amount of rainfall. After the student's initial broad response, Mr. Quim uses multiple following-up talk moves to guide the student to use common terminology and to provide scaffolded cues for the student to connect rainfall duration and amount of rainfall. Like previous instances of narrow responses and broad responses, the following-up-narrow response pairs guide the students to use correct vocabulary or correct investigation activity procedures to establish common experiences for discussion, and the following-up-broad response pairs guide the students in constructing their understanding of the content to elaborate on the students' responses during the classroom discussions.

Pressing and elicited student responses. The teachers use the pressing talk moves to ask students to elaborate on ideas or explanations with further evidence, observations, or personal experiences. As depicted in Table 4.8, there is a higher proportion of pressing-broad response pairs (3.3%) than pressing-narrow response pairs (0.2%), which may occur because elaboration is more likely with multiple possible students' ideas (i.e., broad responses) than with a limited number of correct responses (i.e., narrow responses). The first excerpt demonstrates an example of pressing-narrow response pairs:

Mr. Quim: Okay, what about the ruler, what was that for? Yeah?	Talk move- Following-up
Student 1: Measuring how much rain is on the top.	Narrow response- Activity set-up
Mr. Quim: Measuring how much rain is on top of what?	Talk move- Pressing
Student 1: The concrete and grass. (Lesson 4, Afternoon, February 6, 2019)	Narrow response- Activity set-up

In the first excerpt, Mr. Quim leads the discussion about the available materials and instruments in preparation for the investigation activity that explores the relationship between different types of surface materials and amount of water absorption. Starting with narrow student responses about activity set-up, Mr. Quim uses the pressing talk move to ask the student to elaborate on the response about the different surface materials. The pressing-narrow response pairs clarify the investigation activity procedure for the students. The second excerpt demonstrates an example of pressing-broad response pairs:

Mr. Quim: Ok, so think about duration.	Providing background information
Mr. Quim: And then what else might help us out? And you said something about total amount of water, too, right? Ok, keep going. So, duration and total amount of water. What else? What else do we know based on our evidence?	Talk move- Pressing
Student 1: That it depends on the water.	Broad response- Explanation
Mr. Quim: What is, what is “it” that depends?	Talk move- Pressing
Student 1: That it, that it, that the, um, amount of water has, um, how big the rainfall is.	Broad response- Explanation
Mr. Quim: How big the rainfall is?	Talk move- Pressing
Student 1: Like, how, like, strong or, like, how much rain’s coming down <inaudible>. (Lesson 3, Afternoon, February 5, 2019)	Broad response- Explanation

In the second excerpt, Mr. Quim leads the data analysis discussion to explore the relationship among rainfall duration, hourly rainfall rate, and amount of total rainfall. After the student's initial response, Mr. Quim uses multiple pressing talk moves to ask the student to clarify that the amount of total rainfall depends on the rainfall intensity. Like previous instances of narrow responses and broad responses, the pressing-narrow response pairs guide students' elaboration on their understanding of the investigation activities to establish common experiences for discussion, and the pressing-broad response pairs ask students to clarify and elaborate on their ideas as they identify patterns and construct explanations to maintain classroom discussions.

Restating and elicited student responses. The teachers use the restating talk moves sometimes to emphasize a student's response but most often to ask students to clarify their responses. As depicted in Table 4.8, the proportions for restating-narrow response pairs (2.7%) and for restating-broad response pairs (3.4%) are similar. These similar proportions are reasonable considering the main purpose of the restating talk move to clarify students' responses. The following examples demonstrate the similar use of the restating talk move for clarification purposes. The first excerpt demonstrates an example of restating-narrow response pairs:

Mr. Quim: At the very top there is a scientific question. Your first question, what question are we answering? Can somebody read for us- what question are we trying to answer in this experiment that we're going to do right now? Yeah.	Closed question- Factual recall
Student 1: Which slope will cause the most, and least, water to run off?	Narrow response- Factual recall
Mr. Quim: Which slope will cause the most water and the least water to run off, is that what it says?	Talk move- Restating

Student 1- The most and least water to run off- isn't the high slope the most?	Narrow response- Factual recall
(Lesson 5, Morning, February 13, 2019)	

The second excerpt is an example of restating-broad response pairs:

Ms. Fisi: What else? Any other claims?	Open question- Ideas
Student 1: I think that more absorbent or…	Broad response- Ideas
Ms. Fisi: The more… say that one more time nice and loud.	Talk move- Restating
Student 1: The more absorbent or permeable a surface is, the less water will flow off it.	Broad response- Ideas
(Lesson 4, Afternoon, February 8, 2019)	

As these examples demonstrate, the teachers typically do not use the restating talk moves to elicit multiple student responses and instead use the restating talk moves to clarify student responses. The restating-narrow response pairs and the restating-broad response pairs typically serve a practical purpose in the classroom discussion.

Nominating and elicited student responses. The teachers use the nominating talk move to elicit and mediate student responses by calling on different students to respond to a single teacher question. The nominating talk moves serve similar purposes when mediating narrow responses and broad responses. As depicted in Table 4.8, there is a higher proportion of nominating-broad response pairs (6.7%) than nominating-narrow response pairs (2.0%). This difference is reasonable because it suggests that teachers use nominating talk moves to elicit a higher frequency of multiple responses from broad responses, which have multiple possible responses, than from narrow responses, which have a limited number of correct responses. The following examples demonstrate the similar use of nominating talk moves to mediate narrow responses and broad responses. The first excerpt demonstrates an example of nominating-narrow response pairs:

Mr. Quim: Somebody remind me what was the original challenge? The what?	Closed question- Factual recall
Student 1: The runoff challenge.	Narrow response- Factual recall
Mr. Quim: Can somebody raise their hand, please, so I can call on you?	Non-discussion-related- Logistics
Mr. Quim: Yes, what?	Talk move- Nominating
Student 2: The BUES Runoff Challenge.	Narrow response- Factual recall
(Lesson 2, Afternoon, January 29, 2019)	

The second excerpt is an example of nominating-broad response pairs:

Ms. Fisi: Why do we need to know how much rainfall happened six years ago?	Open question- Ideas
Student 1: So you can like use it <inaudible>, you know how much falls in a long time. If you only like do it for two days, it's, I don't know.	Broad response- Ideas
Ms. Fisi: But you're getting there, you're absolutely getting there. I can tell that you're on the right track. [Student], what'd you think?	Talk move- Nominating
Student 2: Um, cause say one day it might have rained like a lot, and then the next day it might not have rained that much, so you need to go as far back as possible, so like so that at the point where like we can see like all the times that it rained and stuff like that so <inaudible>, last year maybe it didn't rain that much or like, yeah.	Broad response- Ideas
Ms. Fisi: Okay, thank you. [Student].	Talk move- Nominating
Student 3: Maybe to see just how much rain increased or decreased?	Broad response- Ideas
(Lesson 3, Afternoon, February 1, 2019)	

The second excerpt demonstrates that multiple responses are more common with nominating-broad response pairs than with nominating-narrow response pairs. However, in both excerpts, the nominating talk moves elicit additional responses to the initial teacher question and mediate student responses within the discussion. This discussion of question-response pairs and talk move-response pairs focuses on the elicitation of student responses. Understanding students' responses to teacher talk can help teachers determine the types of teacher talk that encourage or inhibit students' responses. In addition to examining the relationship between teacher talk and elicited student responses, it is also important to examine instances the adjustments that teachers make to their questions or talk moves that do not elicit student responses.

Teacher adjustments to no student response. While students typically respond to teacher questions and talk moves, there are some instances when the students do not respond to the teacher talk. As depicted in Table 4.8, the proportion of teacher questions that elicit no student response is low (4.1%). In addition, there are similar proportions of open question-no response pairs (1.9%) and of closed question-no response pairs (2.1%), which suggests that students respond to both types of teacher questions at similar proportions. However, teachers' adjustments when students do not respond to teacher talk can provide further information on the structure of classroom discussion and the types of teacher talk that elicit student responses.

When students do not respond to teacher questions, the teachers adjust their approaches in different ways. These adjustments include rephrasing the question to use a new approach to scaffold the students' understanding, answering the question before the student responds, or asking another student. As depicted in Table 4.9, the highest proportion of teacher adjustments includes rephrasing the question in response to open question-no response pairs (1.2%) and closed question-no response pairs (1.1%). With similar proportions, the next highest proportion of teacher adjustments includes answering the question before a student responds in response to open question-no response pairs (0.7%) and closed question-no response pairs (1.0%). Finally, the lowest proportion of teacher adjustments includes asking another student in response to open

Table 4.9
Summary of types of teacher adjustment to question-no response pairs

	Percentage of Total Teacher Talk/ Student Response Pairs			
	Open		Closed	
Type of Teacher Adjustment	Number of Pairs	Percentage of Pairs	Number of Pairs	Percentage of Pairs
Rephrases question/ New approach	12	1.2%	11	1.1%
Answers question before student responds	7	0.7%	10	1.0%
Asks another student	1	0.1%	1	0.1%

question-no response pairs (0.1%) and closed question-no response pairs (0.1%). The different types of teacher adjustments are described in further detail below.

Rephrasing the question. With teacher question-no response pairs, the highest proportion of teacher adjustments includes a new approach by rephrasing the question or asking a different but related question. For closed question-no response pairs, the teacher typically rephrases the question with a straightforward closed question. The following excerpt is an example of rephrasing a question after a closed question-no response pair:

Mr. Quim: Okay, so we have duration somehow in our, kind of like our formula or basically, you know, our claim.	Talk move- Following-up
Mr. Quim: How do we put in hourly rainfall? How do we put in hourly rainfall?	Closed question- Factual recall (No Student Response)
Ms. Fisi: Is this going to affect the total amount of rain?	Closed question- Yes/no
Student 1: Yes	Narrow response- Yes/no
Ms. Fisi: Yeah?	Talk move- Restating
(Lesson 3, Morning, February 6, 2019)	

In this example, the classroom discussion centers on developing the claim for the scientific argument, which is that the product of rainfall duration and hourly rainfall rate yields amount of total rainfall. Mr. Quim begins with a reminder that rainfall duration is part of the claim and then asks how hourly rainfall rate relates to rainfall duration as part of the claim. When no student responds, Ms. Fisi rephrases the question to ask a more direct, yes/no closed question that the student answers. After establishing that hourly rainfall rate affects the amount of total rainfall, the teachers continue the discussion by again asking the students about the connection to hourly rainfall rate and rainfall duration in relation to amount of total rainfall, and the student is able to answer correctly. In response to closed question-no response pairs, the teachers typically ask a more direct, straightforward closed question that relates to the original question. In this case, the yes/no closed question rephrases the factual recall closed question and assists students in determining a common experience as a reference for their classroom discussion.

For open question-no response pairs, the teacher typically rephrases the open question, which elicits multiple broad responses, with a new approach to the question by asking a more direct, closed question, which elicits limited narrow responses. The excerpt below is an example of rephrasing a question after an open question-no response pair:

Ms. Fisi: You have evidence, what do your numbers say? [Student]?	Open question- Description (No Student Response)
Ms. Fisi: Oh, come on! Okay.	Non-discussion-related- Logistics
Ms. Fisi: Let me ask you this. Which ones absorbed the most water?	Closed question- Factual recall
Student 1: Grass!	Narrow response- Factual recall
Ms. Fisi: How do you know?	Talk move- Following-up
Student 1: Because we tested it.	Broad response- Description
Ms. Fisi: Because you tested it.	Talk move- Restating
(Lesson 4, Morning, February 12, 2019)	

In this example, Ms. Fisi begins with an open question about data observations after the investigation activity that explores different surface materials and their amounts of water absorption. When students do not respond, Ms. Fisi adjusts the approach and asks a closed question that directs the students to review their data observations. This closed question eliminates any potential ambiguity from the initial, open question and guides the students to consider their common experiences of the investigation activity and the data observations. In response to open question-no response pairs, the teachers typically ask a closed question to guide students to an answer so that the students can establish a common experience for and participate more fully in the classroom discussions.

Teacher answers question. In addition to rephrasing the questions, the second-highest proportion of adjustments to teacher question-no response pairs is answering the questions. The following examples represent the teacher providing answers after no student responds. The first excerpt is an example of the teacher's response after a closed question-no response pair:

Ms. Fisi: So, fifteen hundredths is the absorption rate, now exactly what does that mean?	Closed question- Factual recall (No Student Response)
Ms. Fisi: It means that if I pour one inch of water, fifteen hundredths of that water would be absorbed.	Providing content information
(Lesson 4, Afternoon, February 7, 2019)	

The second excerpt is an example of the teacher providing a response after an open question-no response pair:

Mr. Quim: I'm just thinking we've talked about heavy rain, what does that mean?	Open question- Ideas (No Student Response)
Mr. Quim: Like to you heavy rain might be one inch of rain an hour but to me heavy rain might be five inches of rain an hour.	Providing content information
(Lesson 2, Afternoon, January 29, 2019)	

In both examples, the teachers respond to their own questions when the students do not respond. However, there is a limitation with this finding since the data analysis only considers the text and not the length of time of the whole-class discussion, so the amount of time between the teachers' initial questions and the teachers' responses to their own questions is unclear. If teachers answer the questions after a period of wait time for the students to respond, then answering their own questions may be a way to move the whole-class discussion to a different concept. If the teachers answer the questions after little to no wait time, then answering their own questions may have been a rhetorical tool or a practical measure to reach a stopping point in the lesson before the end of the class meeting. While the reasons for teachers' responses to their own questions are unclear, it is possible that this adjustment potentially inhibits student participation in the classroom discussion unlike the other forms of teacher talk.

New student. Finally, with teacher question-no response pairs, the lowest proportion of teacher adjustments includes asking another student when the first student does not respond. These adjustments are similar for closed question-no response pairs and open question-no response pairs, so only one example is provided. The following excerpt is an example of the teacher's adjustment to ask a new student:

Ms. Fisi: As a reminder, what is runoff again? What's runoff? [Student 1]? That's okay.	Closed question- Factual recall (No Student Response)
Ms. Fisi: [Student 2]?	Talk move- Nominating
Student 2: Water kind of going down hills or sinking <inaudible>	Narrow response- Factual recall
Ms. Fisi: Okay, water kind of going down hills or you know kind of sinking- not sinking… but water just kind of running around and like sitting on top, right. (Lesson 3, Morning, February 5, 2019)	Talk move- Restating

In this example, Ms. Fisi asks a closed question about water runoff and nominates Student 1 to respond. When Student 1 does not respond, Ms. Fisi nominates Student 2, who answers the question. Like the other adjustments, this adjustment to the teacher question-no response pair provides a path for the classroom discussion to continue in an environment in which the students have opportunities to speak during discussions but are not forced to participate in discussions.

The first two themes focus on the individual instances of teacher talk and student talk within the whole-class discussion of the SPICE curriculum. The third theme instead focuses on the pairs of teacher talk and the elicited student talk. When considered in aggregate across the science-focused lessons, the proportion of closed question-narrow response pairs is greater than the other proportions of teacher talk-student response pairs, which aligns with the predominance of closed questions within the discussion-related talk. In addition, talk moves elicit a higher proportion of broad responses than narrow responses, which suggests that talk moves tend to extend classroom discussion through broad responses rather than elicit limited student responses. However, all types of teacher talk are part of the classroom discussion. The closed question-narrow response pairs tend to establish common experiences to which students refer during classroom discussions, such as review of previously learned content, common terminology, or investigation activity procedures. The open question-broad response pairs and the talk move-broad response pairs provide students with opportunities to elaborate on their responses within the classroom discussion. Finally, the teacher question-no response pairs demonstrate the flexibility of the teachers during the classroom discussions to adjust their teacher talk to elicit student responses and draw students into classroom discussions as frequently as possible. Therefore, while teacher talk may elicit either limited or extended responses, different kinds of teacher talk serve different purposes within the structure of the classroom discussion. In addition to examining the individual instances of teacher talk and student talk and the pairs of teacher talk and elicited student responses, the question sequences that include groupings of multiple pairs of teacher talk and elicited student responses that serve a common purpose are also examined.

Theme 4: Different Proportions of Closed/ Open Questions for Question Sequences

In the previous theme, teacher talk-student response pairs are explored to describe the types of teacher talk and the elicited student responses. Closed questions tend to elicit narrow responses, open questions tend to elicit broad responses, and talk moves more frequently elicit broad responses. However, as previously discussed, teachers use different teacher talk-student response pairs in complementary ways. For example, closed questions elicit narrow responses that establish common experiences that students subsequently elaborate on through the mediation of open questions and talk moves. Also, after open question-no response pairs, teachers may adjust by asking more direct, closed questions. Therefore, the different teacher talk-student response pairs often complement rather than detract from each other. Data analysis suggests that different proportions of teacher talk-student response pairs combine into different groupings of teacher talk and student talk depending on the purpose of the larger question sequence.

Question sequences. The question sequences are sections of the classroom discussion that relate to the purpose of teacher questioning. The sequence of dialogue typically begins with the teacher asking an initial question, providing background information, or activating prior knowledge. These sequences continue with exchanges of teacher talk and student talk until the teacher makes a summative statement, begins a new activity, or asks a new question that signals the start of a new question sequence with a different conceptual purpose. As depicted in Table 4.10, there are 11 types of question

Table 4.10
Summary of frequency and percentage of instances and teacher talk-student talk pairs of each question sequence

Type of Question Sequence	Number of Instances	Percentage of Total Instances	Number of Pairs	Percentage of Total Number of Pairs
Total	151		1033	
Review	19	12.6%	81	7.8%
Activity set-up/enactment	21	13.9%	135	13.1%
Defining terms	13	8.6%	57	5.5%
Data and observations	19	12.6%	145	14.0%
Describing concepts	22	14.6%	138	13.4%
Design challenge	12	7.9%	107	10.4%
Argumentation	25	16.6%	235	22.7%
Claim	9	6.0%	87	8.4%
Evidence	7	4.6%	71	6.9%
Reasoning	9	6.0%	77	7.5%
Patterns	7	4.6%	30	2.9%
Comparing models	7	4.6%	77	7.5%
Predictions	3	2.0%	15	1.5%
Personal experiences	3	2.0%	17	1.6%

sequences that emerge from the transcript data. These different question sequences include Review, Activity Set-Up and Enactment, Defining Terms, Data and Observations, Describing Concepts, Design Challenge, Argumentation, Patterns, Comparing Models, Predictions, and Personal Experiences. The Argumentation question sequence is further divided into the components of scientific explanation (i.e., Claim, Evidence, Reasoning) based on the discussions that coincide with the curricular activities which identify and specify the three different scientific arguments that are the lesson objectives for Lesson 3, Lesson 4, and Lesson 5.

Frequency of instances of question sequences. As depicted in Table 4.10, the proportion of total instances of question sequences represents one measure of frequency of question sequences. The highest proportion of instances of question sequences is

Argumentation (16.6%), and this question sequence is sub-divided into the Claim, Evidence, and Reasoning question sequences. The next highest proportion of instances of question sequences include Describing Concepts (14.6%) and Activity Set-Up and Enactment (13.9%). The two question sequences with the lowest proportions of instances are Predictions (2.0%) and Personal Experiences (2.0%).

Proportions of question-response pairs in question sequences. Table 4.10 also depicts the proportion of teacher talk-student talk pairs for each type of question sequence. Similar to the over-representation of teacher talk compared to student talk based on the proportion of the number of sentences as opposed to the proportion of turns of talk within the whole-class discussion, each question sequence includes a different number of teacher talk-student talk pairs, so the individual instances of question sequences may over-represent question sequences with fewer teacher talk-student talk pairs. The proportion of the teacher talk-student talk pairs used in question sequences provides additional information to supplement the proportions of the instances of question sequences. The question sequence with the highest proportion of teacher talk-student talk pairs is Argumentation (22.7%), which is in line with the highest proportion of instances of question sequences. The question sequences with the lowest proportion of teacher talk-student talk pairs are Personal Experiences (1.6%) and Predictions (1.5%), which align with the lowest proportions of instances of question sequences. Therefore, while each question sequence includes a different number of teacher talk-student talk pairs, the order of the proportions of instances and of teacher talk-student talk pairs for each question sequence are similar, with higher proportions of instances of question sequences corresponding with higher proportions of teacher talk-student talk pairs.

Question sequences and elicited student responses. Each question sequence includes exchanges between teacher talk and student talk. As previously discussed, the closed questions more frequently elicit narrow responses, and the open questions and talk moves more frequently elicit broad responses. In addition, the teachers use teacher questions and talk moves for certain instructional purposes to guide students in their construction of scientific knowledge. These groupings of teacher questions and talk moves and the elicited student responses that align with a common instructional goal (e.g., defining new vocabulary; describing and analyzing data and observations from investigation activities; making connections to personal experiences) are considered as common question sequences. To describe the instructional goals associated with different types of student responses, the question sequences are divided into three categories: question sequences that elicit higher proportions of narrow student responses, question sequences that elicit similar or balanced proportions of narrow and broad student responses, and question sequences that elicit higher proportions of broad student responses. The descriptions of the categories of question sequences and their proportions of elicited student responses illustrate the relationship between instructional goal and type of student response in the classroom discussion (i.e., limited student participation with narrow responses or extended student participation with broad responses). Since the following tables do not include proportions of mis-matched pairs, teacher talk-question response pairs, or teacher talk-no response pairs, the proportions do not add to 100.0%.

Question sequences with higher proportions of narrow responses. Question sequences that elicit higher proportions of narrow student responses are defined as including at least 60.0% of teacher talk-student response pairs as closed question-narrow response pairs or as talk move-narrow response pairs. The two categories of question sequences with higher proportions of narrow student responses are the Review question sequence and the Activity Set-Up and Enactment question sequence. Both categories of question sequence are described below.

Review. The Review question sequence includes questions that activate students' prior knowledge or that refer to content information from previous lessons (e.g., science, mathematics). Teachers use these questions to prepare for the current lesson or to check students' understanding of content from previous lessons. As depicted in Table 4.11, the Review question sequence is primarily associated with a high proportion of teacher talk-narrow response pairs (92.6%) and a low proportion of teacher talk-broad response pairs (4.9%). There is a high proportion of closed question-narrow response pairs (74.1%) and a low proportion of talk move-narrow response pairs (18.5%), suggesting that the teachers do not use a high frequency of talk moves to extend the classroom discussion through additional student responses after the initial closed question because these closed questions elicit a single correct answer and no further explanation is necessary. The highest proportion of the closed question-narrow response pairs (59.3%) relate to factual recall. For teacher talk-broad response pairs, there is a low proportion of open question-broad response pairs (4.9%), and there are no instances of talk move-broad response pairs. Therefore, the Review question sequence primarily incorporates closed question-narrow response pairs, and this finding aligns with the purpose of the Review question sequence to refer to or recall content information from previous lessons.

Activity set-up and enactment. The Activity Set-Up and Enactment question sequence includes questions that relate to the investigation activities, including the

Table 4.11
Summary of teacher talk-student response pairs for question sequences that primarily elicit narrow responses

Type of Pairs	Percentage of Teacher Talk/ Student Responses Pairs	
	Review	Activity Set-Up
Total pairs per sequence	81	135
Total, Narrow response	92.6%	64.4%
Closed question/ Narrow response	74.1%	51.1%
Yes/no	3.7%	9.6%
Factual recall	59.3%	17.8%
Design decision; activity set-up	11.1%	23.7%
Talk move/ Narrow response	18.5%	13.3%
Following-up	9.9%	8.9%
Pressing	-	0.7%
Restating	4.9%	1.5%
Nominating	3.7%	2.2%
Total, Broad response	4.9%	28.9%
Open question/ Broad response	4.9%	18.5%
Ideas	2.5%	14.1%
Prediction	-	-
Description	2.5%	4.4%
Explanation	-	-
Talk move/ Broad response	-	10.4%
Following-up	-	3.7%
Pressing	-	3.7%
Restating	-	1.5%
Nominating	-	1.5%

guiding questions, the procedures, the materials and instruments, and the data collection and representations. Teachers use these questions to prepare students to enact the investigation activities safely. As depicted in Table 4.11, the Activity Set-Up and Enactment question sequence is primarily associated with a high proportion of teacher talk-narrow response pairs (64.4%) and a low proportion of teacher talk-broad response pairs (28.9%), which suggests that teachers ask questions with limited response options as they discuss safe and proper procedures during the investigation activities with the students. Most teacher talk-narrow response pairs are closed question-narrow response pairs (51.1%) compared to talk move-narrow response pairs (13.3%), which suggests that teachers do not use a high frequency of talk moves to extend discussions after the initial closed question. As expected, the highest proportion (23.7%) of closed question-narrow response pairs corresponds to activity set-up. For teacher talk-broad response pairs, there are low proportions of open question-broad response pairs (18.5%) and of talk move-broad response pairs (10.4%). Therefore, in the Activity Set-Up and Enactment question sequence, the teachers primarily use closed questions that focus on previously determined investigation activity procedures and uses of materials and instruments.

Question sequences with similar proportions of narrow and broad responses. Question sequences that elicit similar proportions of narrow student responses and broad student responses are defined as including less than 60.0% of teacher talk-student response pairs as closed question-narrow response pairs or as talk move-narrow response pairs and less than 60.0% of teacher talk-student response pairs as open question-broad response pairs or as talk move-broad response pairs. The five categories of question sequences with similar proportions of narrow student responses and broad student responses include the Defining Terms question sequence, the Describing Concepts question sequence, the Data and Observations question sequence, the Design Challenge question sequence, and the Argumentation question sequence. These categories of question sequence are described below.

Defining terms. The Defining Terms question sequence includes questions that introduce terminology and vocabulary for the current lesson's concepts and activities. Teachers use questions to elicit student responses that identify and describe scientifically correct definitions of these terms. As depicted in Table 4.12, the Defining Terms question sequence is associated with a higher proportion of teacher talk-narrow response pairs (59.6%) and a lower proportion of teacher talk-broad response pairs (38.6%). There is a high proportion of closed question-narrow response pairs (49.1%) compared to a low proportion of talk move-narrow response pairs (10.5%), suggesting that the teachers do not use a high frequency of talk moves to extend classroom discussions that begin with a closed question. The highest proportion of the closed question-narrow response pairs (35.1%) relates to factual recall, which aligns with the purpose of the Defining Terms question sequence to introduce and correctly define scientific terms. There is a lower proportion of open question-broad response pairs (28.1%), and the highest proportion of these pairs relates to eliciting student ideas (26.3%), which corresponds to teacher talk that elicits students' descriptions about the scientific terms. Asking closed questions that elicit factual recall to check students' understanding of the definition of the scientific terms and open questions that elicit students' ideas to activate prior knowledge about scientific terms aligns with the balanced proportions of narrow and broad responses for the Defining Terms question sequence.

Describing concepts. The Describing Concepts question sequence includes questions that introduce a concept or develop a relationship between concepts (e.g., rainfall, absorption, runoff). Teacher talk activates prior knowledge from students' personal experiences, previous investigation activities, and prior classroom discussions to

Table 4.12
Summary of teacher talk-student response pairs for question sequences that elicit narrow and broad responses

	Percentage of Teacher Talk/ Student Response Pairs				
Type of Pairs	Defining Terms	Describing Concepts	Data and Observations	Design Challenge	Argumentation
Total pairs per sequence	57	138	145	107	235
Total, Narrow response	59.6%	58.0%	57.9%	42.1%	34.5%
Closed question/ Narrow response	49.1%	45.7%	46.9%	30.8%	27.2%
Yes/no	14.0%	12.3%	10.3%	15.0%	10.6%
Factual recall	35.1%	32.6%	35.9%	8.4%	15.7%
Design decision; activity set-up	-	0.7%	0.7%	7.5%	0.9%
Talk move/ Narrow response	10.5%	12.3%	11.0%	11.2%	7.2%
Following-up	3.5%	5.8%	6.9%	3.7%	4.7%
Pressing	-	-	-	-	-
Restating	5.3%	2.9%	2.8%	4.7%	1.3%
Nominating	1.8%	3.6%	1.4%	2.8%	-
Total, Broad response	38.6%	36.2%	37.9%	48.6%	55.7%
Open question/ Broad response	28.1%	17.4%	17.2%	24.3%	30.2%
Ideas	26.3%	15.9%	7.6%	15.9%	20.9%
Prediction	-	-	-	-	-
Description	1.8%	1.4%	9.7%	2.8%	4.3%
Explanation	-	-	-	5.6%	5.1%
Talk move/ Broad response	10.5%	18.8%	20.7%	24.3%	25.5%
Following-up	1.8%	9.4%	4.1%	5.6%	11.1%
Pressing	1.8%	1.4%	3.4%	4.7%	2.6%
Restating	3.5%	2.2%	2.8%	3.7%	5.5%
Nominating	3.5%	5.8%	10.3%	10.3%	6.4%

engage students in describing concepts and making connections with related content information. As depicted in Table 4.12, the Describing Concepts question sequence is primarily associated with a higher proportion of teacher talk-narrow response pairs (58.0%) and a lower proportion of teacher talk-broad response pairs (36.2%). There is a high proportion of closed question-narrow response pairs (45.7%) compared to talk move-narrow response pairs (12.3%), suggesting that teachers use individual closed questions more frequently than talk moves to engage students in classroom discussions. The majority of these closed question-narrow response pairs relate to factual recall and establish common understandings among the students about new concepts (e.g., surface materials, water absorption, water runoff). For the teacher talk-broad response pairs, there are similar proportions of open question-broad response pairs (17.4%) and talk move-broad response pairs (18.8%). These similar proportions suggest that teachers use both open questions and talk moves to extend classroom discussions that elicit broad responses. Most open question-broad response pairs in the classroom discussions elicit students' ideas (15.9%) to assist students in making connections among the concepts. The teachers also extend classroom discussion through following-up-broad response pairs (9.4%) and nominating-broad response pairs (5.8%). To align with the purpose of the Describing Concepts question sequences, teachers use balanced proportions of closed questions to set up the classroom discussions and of open questions and talk moves to extend student participation and to guide students with making connections among the concepts in the classroom discussions.

Data and observations. The Data and Observations question sequence includes questions that focus on descriptions, discussions, and calculations of the data and observations that students collect and analyze during the investigation activities. As depicted in Table 4.12, the Data and Observations question sequence is primarily associated with a higher proportion of teacher talk-narrow response pairs (57.9%) and a lower proportion of teacher talk-broad response pairs (37.9%). There is a high proportion of closed question-narrow response pairs (46.9%) compared to talk move-narrow response pairs (11.0%), suggesting that teachers ask initial closed questions more frequently than they use talk moves to extend the classroom discussions after a narrow response. Most closed question-narrow response pairs (35.9%) relate to factual recall, which aligns with describing and recalling the procedures and results of data collection. For the teacher talk-broad response pairs, there are similar proportions of open question-broad response pairs (17.2%) and talk move-broad response pairs (20.7%). Most open question-broad response pairs center on describing observations (9.7%) and eliciting ideas about data collection and data analysis (7.6%). The higher proportion of talk move-broad response pairs compared to open question-broad response pairs suggests that students engage in extended discussions about data and observations after an initial open question, such as with multiple students sharing their data observations, calculations, and analyses through teacher-mediated nomination-broad response pairs (10.3%). In alignment with the purpose of the Data and Observations question sequence, teachers use closed questions to establish procedures for data collection and open questions and talk moves to extend classroom discussions and to provide opportunities for students to describe their observations and to discuss their calculations and analyses.

Design challenge. The Design Challenge question sequence includes questions that introduce and discuss the water runoff design challenge. The teachers and students discuss the design constraints (e.g., number and location of buildings; types of surface materials; cost of materials; strength of design to withstand intense rainfall). The teachers and students also discuss the computer program used to create the models, but they do not describe or compare their models during these question sequences. As depicted in Table 4.12, the Design Challenge question sequence is primarily associated with a higher proportion of teacher talk-broad response pairs (48.6%) and a slightly lower proportion of teacher talk-narrow response pairs (42.1%). There is a high proportion of closed question-narrow response pairs (30.8%) compared to talk move-narrow response pairs (11.2%), suggesting that teacher do not frequently use talk moves to extend classroom discussions after an initial closed question. Of the closed question-narrow response pairs, the pairs that focus on factual recall (8.4%) tend to recall content from previous lessons (e.g., the amount of water absorption by different surface materials) that can inform design decisions, and the pairs that elicit yes/no binary responses (15.0%) and design decision responses (7.5%) guide the students in making group and individual decisions about their water runoff model designs. For the teacher talk-broad response pairs, there are equal proportions of open question-broad response pairs (24.3%) and talk move-broad response pairs (24.3%), which suggest that teachers use both open questions and talk moves to extend classroom discussions that elicit broad responses. Most open question-broad response pairs elicit students' ideas (15.9%) about how to address the water runoff problem within the constraints of the design, and the teachers use nominating-broad response pairs (10.3%) to elicit multiple students' ideas about the design decisions. In alignment with purpose of the Design Challenge question sequence, teachers use closed questions to establish the common design constraints and open questions and talk moves to extend student participation in the classroom discussion and to elicit ideas for multiple solutions to the design challenge.

Argumentation. The Argumentation question sequence includes questions that guide students in generating a scientific explanation of a phenomenon with the use of predictions, data and observations, and justifications. Each argument includes the three sub-components of argumentation (i.e., claim, evidence, reasoning). In these lessons, the claim answers the scientific questions proposed during the investigation activities with a mathematical relationship (e.g., the product of hourly rainfall rate and rainfall duration yields amount of total rainfall). The evidence includes descriptions of the data and observations from the investigation activities that answer the scientific question. The reasoning includes a justification of why the evidence supports the claim. These question sequences describe the classroom discussions that correspond to the three components of argumentation that the curriculum identifies for each investigation activity.

As depicted in Table 4.12, the Argumentation question sequence is primarily associated with a higher proportion of teacher talk-broad response pairs (55.7%) and a lower proportion of teacher talk-narrow response pairs (34.5%), which suggests that open questions and talk moves extend student talk in classroom discussion through broad responses. The teacher talk-narrow response pairs include lower frequencies of closed question-narrow response pairs (27.2%) and talk move-narrow response pairs (7.2%). Most closed question-narrow response pairs elicit factual recall (15.7%) or yes/no binary (10.6%) responses, which align with recalling data and observations from investigation activities to develop claims or to support claims through evidence. For the teacher talk-broad response pairs, there are similar proportions of open question-broad response pairs

(30.2%) and talk move-broad response pairs (25.5%), again suggesting like previously discussed question sequences that teachers use open questions to elicit broad response and use talk moves to build on open responses to guide students to a deeper understanding of concepts. Most open question-broad response pairs elicit students' ideas (20.9%) as students explore and analyze data and observations from the investigation activities to develop and justify the mathematical argumentation claims. In these Argumentation question sequences, the teachers use balanced proportions of teacher talk-narrow response pairs and teacher talk-broad response pairs as the teachers guide students through exploring the data and observations from investigation activities to develop claims, identify evidence, and justify the claims through reasoning. In addition to the Argumentation question sequence as a whole, the question sequences for the argumentation components are also explored.

The Argumentation question sequence includes similar proportions of teacher talk-narrow response pairs and teacher talk-broad response pairs, with a higher proportion of teacher talk-broad response pairs suggesting the greater frequency of extended broad responses in classroom discussions. The question sequences for the argumentation components (i.e., Claim, Evidence, Reasoning) include similar proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs. As depicted in Table 4.13 though, a trend emerges in the Claim, Evidence, and Reasoning question sequences. Specifically, the teachers guide the students to develop the claim first, then to use evidence to support the claim, and finally to justify the claim with evidence-based reasoning, and this process corresponds to progressively higher proportions of broad, extended student responses in the classroom discussions. The Claim question sequence

Table 4.13
Summary of teacher talk-student response pairs for Argumentation component question sequences (Claim, Evidence, Reasoning)

	Percentage of Teacher Talk/ Student Responses Pairs		
Type of Pairs	Claim	Evidence	Reasoning
Total pairs per sequence	87	71	77
Total, Narrow response	43.7%	36.6%	22.1%
Closed question/ Narrow response	32.2%	29.6%	19.5%
Yes/no	12.6%	7.0%	11.7%
Factual recall	19.5%	22.5%	5.2%
Design decision; activity set-up	-	-	2.6%
Talk move/ Narrow response	11.5%	7.0%	2.6%
Following-up	9.2%	4.2%	-
Pressing	-	-	-
Restating	-	2.8%	1.3%
Nominating	2.3%	-	1.3%
Total, Broad response	41.4%	60.6%	67.5%
Open question/ Broad response	27.6%	32.4%	31.2%
Ideas	23.0%	15.5%	23.4%
Prediction	-	-	-
Description	3.4%	8.5%	1.3%
Explanation	1.1%	8.5%	6.5%
Talk move/ Broad response	13.8%	28.2%	36.4%
Following-up	9.2%	14.1%	10.4%
Pressing	1.1%	-	6.5%
Restating	1.1%	4.2%	11.7%
Nominating	2.3%	9.9%	7.8%

includes balanced proportions of teacher talk-broad response pairs (41.4%) and teacher talk-narrow response pairs (43.7%). The Evidence question sequence includes a higher proportion of teacher talk-broad response pairs (60.6%) compared to teacher talk-narrow response pairs (36.6%). The Reasoning question sequence includes an even higher proportion of teacher talk-broad response pairs (67.5%) compared to teacher talk-narrow response pairs (22.1%). Regarding the teacher talk-broad response pairs, the three question sequences include similar proportions of open question-broad response pairs, but the differences in teacher talk-broad response pairs are associated with progressively larger proportions of talk move-broad response pairs. The Claim question sequence includes relatively low proportions of open question-broad response pairs (27.6%) and talk move-broad response pairs (13.8%). The Evidence question sequence includes higher proportions of open question-broad response pairs (32.4%) and talk move-broad response pairs (28.2%). The Reasoning question sequence includes a higher proportion of open question-broad response pairs (31.2%) and the highest proportion of talk move-broad response pairs (36.4%). The teachers tend to use a lower proportion of closed question-narrow response pairs and a higher proportion of open question-broad response pairs and talk move-broad response pairs as the classroom discussion shifts from developing a claim based on recall of previously learned content to describing evidence through data and observations to justifying a reasoning for the claim by making connections among content instruction, the claim, and the evidence. As the students develop a scientific argument through the successive steps of developing a claim, describing evidence, and justifying reasoning, the classroom discussions shift from limited responses elicited from closed question-narrow response pairs to extended responses associated with open question-broad response and talk move-broad response pairs.

Question sequences with higher proportions of broad responses. Question sequences that elicit higher proportions of broad student responses are defined as including at least 60.0% of teacher talk-student response pairs as open question-broad response pairs or as talk move-broad response pairs. The four categories of question sequences with higher proportions of broad student responses are the Patterns question sequence, the Comparing Models question sequence, the Predictions question sequence, and the Personal Experiences question sequence. These categories of question sequence are described below.

Patterns. The Patterns question sequence includes questions that elicit student responses based on identifying patterns that emerge from data analysis and interpretation rather than from direct data collection and reporting. Teachers use these questions to guide students to determine relationships among different variables based on data collected during the investigation activities (e.g., the relationship between higher slope and greater amount of water runoff). As depicted in Table 4.14, the Patterns question sequence is primarily associated with a higher proportion of teacher talk-broad response pairs (60.0%) and a lower proportion of teacher talk-narrow response pairs (36.7%). There is a high proportion of open question-broad response pairs (40.0%) compared to a lower proportion of talk move-broad response pairs (20.0%), which suggests that teachers use a higher proportion of initial open questions than talk moves to guide students as they construct understandings of patterns in data analysis. For open question-broad response pairs, teachers primarily ask questions to elicit students' ideas (23.3%), which correspond to classroom discussions that focus on analyzing data and identifying patterns. For teacher talk-narrow response pairs, there are low proportions of closed question-narrow response pairs (23.3%) and talk move-narrow response pairs (13.3%), which correspond to low proportions of limited student talk compared to broad, extended student responses. Therefore, teachers use higher proportions of teacher talk-broad response pairs than teacher talk-narrow response pairs, which aligns with the purpose of the Patterns question

Table 4.14
Summary of teacher talk-student response pairs for question sequences that primarily elicit broad responses

Type of Pairs	Percentage of Teacher Talk/ Student Responses Pairs			
	Patterns	Comparing Models	Predictions	Personal Experiences
Total pairs per sequence	30	77	15	17
Total, Narrow response	36.7%	19.5%	26.7%	11.8%
Closed question/ Narrow response	23.3%	15.6%	20.0%	11.8%
Yes/no	13.3%	6.5%	13.3%	11.8%
Factual recall	10.0%	6.5%	6.7%	-
Design decision; activity set-up	-	2.6%	-	-
Talk move/ Narrow response	13.3%	3.9%	6.7%	-
Following-up	10.0%	-	-	-
Pressing	-	1.3%	-	-
Restating	3.3%	1.3%	6.7%	-
Nominating	-	1.3%	-	-
Total, Broad response	60.0%	72.7%	73.3%	88.2%
Open question/ Broad response	40.0%	35.1%	40.0%	35.3%
Ideas	23.3%	20.8%	6.7%	17.6%
Prediction	-	-	33.3%	-
Description	6.7%	14.3%	-	17.6%
Explanation	10.0%	-	-	-
Talk move/ Broad response	20.0%	37.7%	33.3%	52.9%
Following-up	16.7%	14.3%	-	5.9%
Pressing	-	6.5%	6.7%	23.5%
Restating	-	3.9%	6.7%	11.8%
Nominating	3.3%	13.0%	20.0%	11.8%

sequence to guide students as they describe data collected from investigation activities and analyze data to construct understandings about the patterns identified in the data.

Comparing models. The Comparing Models question sequence includes questions that ask students to describe their water runoff design models and any model revisions.

Teachers also ask students to compare their models with other students' models, which provides opportunities for students to evaluate and comment on other students' models. As depicted in Table 4.14, the Comparing Models question sequence is primarily associated with a high proportion of teacher talk-broad response pairs (72.7%) and a low proportion of teacher talk-narrow response pairs (19.5%). There are similar proportions of open question-broad response pairs (35.1%) and of talk move-broad response pairs (37.7%), which suggests that teachers use open questions and talk moves to extend students' broad responses in classroom discussions. The open question-broad response pairs correspond to questions that elicit students' ideas (20.8%) and descriptions (14.3%), which correspond to the students' descriptions of their own models and their evaluations of other students' models. Further, the talk move-broad response pairs primarily include following-up-broad response pairs (14.3%) and nominating-broad response pairs (13.0%) as multiple students participate in the teacher-guided discussions about students' model descriptions and comparisons. For teacher talk-narrow response pairs, there are low proportions of closed question-narrow response pairs (15.6%) and of talk move-narrow response pairs (3.9%). Therefore, teachers use high proportions of open questions and talk moves to elicit broad student responses for students to describe and discuss their water runoff design models, which aligns with the purpose of the Comparing Models question sequence and provides opportunities for students to engage in science talk directly with other students.

Predictions. The Predictions question sequence includes questions that elicit student responses to predict what occurs during investigation activities (e.g., predicting relative amounts of water absorption for different surface materials). Students justify their predictions with personal experiences, previously learned content, or data from investigation activities. As depicted in Table 4.14, the Predictions question sequence is primarily associated with a high proportion of teacher talk-broad response pairs (73.3%) and a low proportion of teacher talk-narrow response pairs (26.7%). There are similar proportions of open question-broad response pairs (40.0%) and of talk move-broad response pairs (33.3%), which suggests that teachers use questions and talk moves to extend students' broad responses in classroom discussions. As expected, most open question-broad response pairs elicit prediction responses (33.3%). In addition, teachers use a high proportion of nominating-broad response pairs (20.0%) to elicit multiple students' responses to make and justify predictions about investigation activities. For teacher talk-narrow response pairs, there are low proportions of closed question-narrow response pairs (20.0%) and of talk move-narrow response pairs (6.7%), which correspond to less limited student talk and more extended student responses. Therefore, teachers use higher proportions of teacher talk-broad response pairs than teacher talk-narrow response pairs, which aligns with the Predictions question sequence in which teachers ask students not to recall content but instead to apply learned content and previous experiences to predict a phenomenon in a new situation.

Personal experiences. The Personal Experiences question sequence includes questions that ask students to describe previous personal experiences, which consist of in-school experiences (e.g., observations of the recess area at BUES where water collects during rainstorms) and out-of-school experiences (e.g., intensity of rainfall). As depicted in Table 4.14, the Personal Experiences question sequence is primarily associated with a high proportion of teacher talk-broad response pairs (88.2%) and a low proportion of teacher talk-narrow response pairs (11.8%). There is a lower proportion of open question-broad response pairs (35.3%) than talk move-broad response pairs (52.9%), which suggests that teachers use a high frequency of talk moves to ask students to elaborate on their responses about their personal experiences. The high combined proportions of following-up-broad response pairs (5.9%) and pressing-broad response pairs (23.5%) align with the teachers' use of talk moves to elicit further information about students' personal experiences and to guide students as they connect their personal experiences to the lesson content. In addition, for teacher talk-narrow response pairs, there is a low proportion of closed question-narrow response pairs (11.8%), and there are no instances of talk move-narrow response pairs. Therefore, teachers use higher proportions of teacher talk-broad response pairs than teacher talk-narrow response pairs as they elicit student responses about personal experiences as opposed to recall of previously learned content.

Like the third theme that centers on the pairs of teacher talk and the elicited student talk, the fourth theme also centers on these pairs but groups them in different question sequences according to their purpose. As discussed in the third theme, when considered in aggregate across the science-focused lessons, the proportion of closed question-narrow response pairs is greater than the proportions of other teacher talk-student response pairs. However, as discussed in this theme, different question sequences include different proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs. Certain question sequences incorporate higher proportions of teacher talk-narrow response pairs to establish common classroom experiences for reference in classroom discussions, such as reviewing previously learned content or setting common procedures for investigation activities. Other question sequences incorporate higher proportions of teacher talk-broad response pairs to provide students with opportunities to describe their personal experiences and to apply and synthesize the content to new situations. Finally, some question sequences incorporate similar proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs, and teachers use different kinds of teacher talk that elicit different kinds of student responses in complementary ways to guide students as they construct their understandings in classroom discussions. Therefore, different kinds of teacher talk serve different purposes within the structure of the classroom discussion. These different purposes are associated with different groupings of teacher talk-student response pairs within different question sequences, and the different types of elicited student responses relate not only to the types of teacher questions but also to the purpose of the teacher questions based on the lesson objective and the focus of the curriculum.

Chapter Summary

In this chapter, I describe research findings based on my analysis of the types of teacher talk and student talk in the whole-class classroom discussions during the SPICE curriculum's science-focused lessons. The research findings relate to four themes: (1) teacher talk and closed-ended questions are predominant in the whole-class discussions; (2) the teacher mediates most student talk during the whole-class discussion; (3) closed-ended teacher talk tends to elicit narrow student responses, and open-ended teacher talk tends to elicit broad student responses, with closed question-narrow response pairs occurring at the highest frequency; and (4) different types of question sequences with different purposes are associated with varying proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs. In the following chapter, I discuss implications of the research findings described above and consider implications and related recommendations within the context of the problem of practice as described in Chapter 1.

CHAPTER 5: DISCUSSION, RECOMMENDATIONS, AND LIMITATIONS

This capstone research study is developed out of an interest in calls for changes to science education to include greater student engagement with the practices of scientists and engineers (NGSS Lead States, 2013; NRC, 2012). Learning takes place in social contexts (Brown et al., 1989; Lave & Wenger, 1991; Wenger, 1998). Learning can occur in a community of practice through social interaction among individuals with a common purpose and common practices (Wenger, 1998), and newcomers to the community of practice learn not from listening to talk but from learning to talk like a member of the community of practice by participating in the community of practice (Lave & Wenger, 1991). Like learning in general, science is also a social endeavor. One practice in which scientists engage is talking science. Scientists develop their ideas collaboratively, communicate their ideas to other scientists, and critique other scientists' ideas. Within the classroom environment, talk can serve an important role in mediating the learning space (Alexander, 2008) of the community of practice between the experts (i.e., the teachers) and the newcomers (i.e., the students) by giving students access to science practices (Mercer et al., 2004), and teacher questioning serves as a means of providing access to and engaging students in classroom talk (Alexander, 2008). As such, I consider the role of classroom talk and classroom discussion through teacher questioning in developing students' participation in the practice of science.

Classroom discussions vary in terms of their quality. Teacher guidance and scaffolding play an important role in helping students to participate in productive classroom discussions (Chin & Osborne, 2010; Hogan et al., 1999; McNeill, 2011; Mercer et al., 2004; Monteira & Jiménez-Aleixandre, 2016). Teachers use questions to guide these discussions (Kawalkar & Vijapurkar, 2013) to enable students to use classroom talk for thinking and reasoning (Chin, 2006). In high-quality discussions that focus on students' thinking, teachers typically ask open questions to encourage engagement in classroom discussions and other authentic practices, promote higher-level critical thinking, and elicit longer student responses that involve deeper reasoning (Colley & Windschitl, 2016; Edmondson & Choudhry, 2018; Erdogan & Campbell, 2008; Martin & Hand, 2009; McNeill & Pimentel, 2010; Oliveira, 2010). However, closed questions can also serve pedagogical purposes, such as checks for understanding (Ho, 2005), so high-quality discussions that elicit rigorous talk can stem from an appropriate mix of higher-cognitive-demand open questions and lower-cognitive-demand closed questions (Chin, 2006; Windschitl et al., 2018) rather than from only open questions. Teachers also utilize talk moves, such as following-up and pressing, in high-quality discussions to be responsive to student talk (Chinn et al., 2001; Murphy, 2007; Rojas-Drummond & Mercer, 2004; Thompson et al., 2016; van Zee & Minstrell, 1997) and to prompt students to add to their responses or explain their reasoning in greater detail (Chinn et al., 2001; Scott et al., 2006). Therefore, teachers use appropriate combinations of open and closed questions and talk moves to engage students to participate in high-quality discussions.

In addition to teacher questions and talk moves, other teaching practices engage students in high-quality discussions. Just as teachers plan curricular activities for their lessons, teachers plan for the goals of classroom discussions as part of their lessons (Windschitl et al., 2018). Determining the purpose of the classroom discussion ahead of time provides teachers with the opportunities to choose tools and routines that align with the instructional goal of the discussion (Windschitl et al., 2018). During classroom discussion, teachers make explicit connections to science practices (Windschitl et al., 2018) and verbalize these connections to students so that students can see themselves as scientists. Finally, high-quality discussions often combine hands-on activities with classroom discussions (Murphy, 2007; Windschitl et al., 2018). Therefore, high-quality discussions elicit high-quality student talk through various teacher practices.

Since students are newcomers to the practice of science, I consider the role of teachers and teacher questioning in engaging students in classroom discussion and student-student talk within the implementation of an integrated STEM project from the SPICE curriculum in two fifth-grade classrooms. In the first chapter, I situate this study within a problem of practice regarding how teachers can position themselves as outside the central focus of the classroom discussion as they guide student participation in the classroom discussion through teacher questioning and other talk moves within the specific context of the SPICE curriculum. The SPICE curriculum represents the community of practice because it serves as the context of the interaction between teachers and students who have a common purpose of generating water runoff models to limit the amount of water that pools in the recess area at BUES with common terms and practices, such as using evidence and engaging in scientific argumentation. In the second chapter, I discuss relevant literature related to the practice of science, students' learning of science, classroom discussions, and teacher questioning. In the third chapter, I describe my methodological processes, including data analysis through deductive descriptive coding and inductive pattern coding of the text transcripts from the science-focused lessons of the SPICE curriculum. In the fourth chapter, I detail findings that align to the research question posed within this study. In this chapter, I discuss the research findings, describe implications related to this study, and provide recommendations specific to the context of the study that could be used to support teacher talk and student talk within classroom discussions at BUES and in future iterations of the SPICE curriculum. In addition, I address limitations of this study and reflect on the capstone research experience.

Findings for this study relate to the following research question and sub-questions regarding the relationship between teacher questioning and the elicited student responses.

(1) What kinds of teacher questioning and opportunities for student response are present in the discussions during the enactment of the SPICE curriculum?

    a. In whole-class discussions, what is the frequency of teacher questioning as compared to student response?

    b. In whole-class discussions, to what extent do frequency and kind of teacher questioning as compared to student response differ by lesson?

    c. In whole-class discussions, what kinds of questions do teachers ask, and what kinds of student responses do these questions elicit?

Four themes emerge from the whole-class discussion data. The first theme describes the predominance of teacher talk and closed questions in the whole-class discussions and aligns with the first and second research sub-questions. The second theme describes the predominance of teacher-mediated student talk during the whole-class discussion and aligns with the second and third research sub-questions. The third theme describes the alignment of closed teacher questions and narrow student responses and of open teacher questions and broad student responses, and the fourth theme describes different groupings of teacher talk-narrow response pairs and of teacher talk-broad response pairs depending on the instructional goal of the question sequence. The third and fourth themes both align with the third research sub-question. These findings, related implications, and recommendations are discussed in this chapter.

Discussion and Recommendations

Predominance of teacher talk and closed questions. In alignment with the first and second research sub-questions, the first theme from the findings asserts that the teachers speak more than the students during the science-focused lessons of the SPICE curriculum. The first theme also asserts that the teachers utilize a higher frequency of teacher questions than teacher talk moves and that the teachers utilize a higher frequency of closed questions than open questions to elicit student responses. A further discussion of the first theme and the related implications and recommendations follows below.

Discussion-related teacher talk. When looking at the classroom talk of the SPICE curriculum, there is a higher frequency of discussion-related talk (i.e., teacher questions, teacher talk moves, student responses) that relate to the lesson objectives and curricular activities and a lower frequency of non-discussion-related talk (i.e., logistics, activity set-up, telling information) that relate to classroom management and setting up investigation activities. This distinction between discussion-related talk and non-discussion-related talk suggests that most of the classroom talk during the science-focused lessons focuses on the lesson objectives and on engaging students in constructing understandings about water runoff through classroom discussion. Within the discussion-related talk, teachers engage students to participate in classroom discussion using various methods like teacher questions and talk moves, but they use teacher questions at a higher frequency than they use talk moves, which suggests that teachers pursue new lines of questioning with new teacher questions rather than support students' responses and ask students to elaborate on their responses. Further, teachers use the closed and open questions complementarily but ask more closed questions than open questions, and this higher frequency of closed questions suggests that teachers ask more lower-cognitive-demand questions during the science-focused lessons. Therefore, the teachers encourage student talk in the classroom discussions, but the student talk consists of more responses to teacher questions than responses that build on previous student responses through the management of talk moves and of more responses to lower-cognitive-demand closed questions than responses to higher-cognitive-demand open questions. However, it is important to emphasize that, regardless of cognitive demand, the teacher talk engages the students to participate in the classroom discussion.

Within the individual, science-focused lessons, there are similar findings to the aggregated discussion-related talk. For the four science-focused lessons, each lesson follows a similar structure that begins with a discussion about the content and ends with a discussion about the student-generated models. As previously discussed, the main differences among the lessons are the number of class meetings and the discussed content. Lesson 2 lasts one class meeting while each of the other three lessons lasts more than one class meeting. Lesson 2 reviews the water runoff model design challenge and introduces the computer program that the students use to design their water runoff models while the other lessons incorporate investigation activities and provide time for students to revise their water runoff models. Like the aggregated findings, each lesson includes a higher frequency of teacher questions than talk moves and a higher frequency of closed questions than open questions. However, teachers ask more questions during Lesson 2 than during the other lessons. The teachers use Lesson 2 to introduce the curricular activities, such as the curricular objective of determining water runoff and the computer program used to design the water runoff models, so that the students become more familiar with the content and the tools and require less teacher guidance during the later lessons. Considering the differences among the lessons through this lens, the teachers use more teacher questions to guide the discussion during Lesson 2 so that the teachers and students have more opportunities to discuss the students' data observations and analyses from the investigation activities and the students' water runoff models in the later lessons.

Although the classroom talk in the science-focused lessons is primarily related to discussion, teachers use a higher frequency of teacher questions than teacher talk moves and a higher frequency of closed questions than open questions. The teacher talk engages the students in the discussion, but the higher frequency of lower-cognitive-demand closed questions suggests that the teachers serve as the primary voices of the lesson (Bleicher et al., 2003; Mercer, 2010; Pimentel & McNeill, 2013) through teacher-centered instruction. However, even with a higher frequency of closed questions, the teachers' use of open questions and talk moves throughout the lessons to focus on student thinking and to encourage students to elaborate on their reasoning and explanations instead suggests that the teachers engage in teacher-guided instruction (Chin, 2006; Hogan et al., 1999). As the teachers utilize open questions at a higher frequency, the students engage in higher-cognitive-demand thinking (Ernst-Slavit & Pratt, 2017; McNeill & Pimentel, 2010), participate in classroom discussions with deeper understanding of the content (Edmondson & Choudhry, 2018), and become partners in the discussion with their teachers and with their fellow students (Oliveira, 2010). Open questions also encourage students to participate in student-student talk within classroom discussions (McNeill & Pimentel, 2010). Since the participating teachers utilize closed questions, open questions, and talk moves to engage students in the classroom discussion, the instruction can be characterized as teacher-guided rather than teacher-centered. As the teachers utilize higher frequencies of open questions and talk moves, they promote deeper classroom discussion and center the instruction more and more on students' thinking and reasoning.

Recommendations for discussion-related teacher talk. Both closed questions and open questions are present in high-quality discussions, but high-quality discussions typically include higher frequencies of open questions. The following section addresses recommendations for the participating teachers and for teachers in general to utilize higher frequencies of open questions within classroom discussions.

Professional development opportunities. Professional development opportunities can support teachers as they practice discussion or scientific talk in smaller groups outside the classroom environment. The participating classroom teacher and STEM specialist do not have a typical relationship with science as elementary teachers. Most elementary teachers either are not familiar or are not comfortable with science talk and science content. Each participating teacher from BUES instead has a collegiate background in science and multiple years of experience teaching science. This experience with science may influence the participating teachers' use of open questions and talk moves within the classroom discussion since science teachers who are unfamiliar with the content tend to talk more than students during classroom discussions, ask questions frequently, and use primarily lower-cognitive-demand closed questions (Carlsen, 1993). Professional development may provide teachers with opportunities to familiarize themselves with science talk and with high-quality discussion.

During professional development, typical elementary teachers who are not as familiar with science talk or with science content can practice high-quality discussion and scientific talk in smaller groups. Administrators and experienced science teachers may lead these professional development sessions by giving teachers topics to discuss and guiding teachers through a classroom discussion with closed questions and open questions. Through these practice discussions, the administrators and experienced science teachers model teacher questions and talk moves as part of a high-quality discussion. These practice discussions may also reflect upcoming topics within the teachers' science lessons so that the teachers can anticipate students' misconceptions and prepare for opportunities in the classroom talk that connect more readily with extended discussion. The teachers attending the professional development can discuss the effectiveness of closed and open questions and, as part of planning for classroom discussions, develop a selection of teacher questions and talk moves that they use to guide their students within the classroom discussion (Windschitl et al., 2018). Preparing teacher questions and talk moves ahead of time can help teachers who are either experienced or unfamiliar with science to guide students in their reasoning.

Explicit connections to high-quality discussion. In addition to practicing classroom discussions during professional development opportunities, teachers can also make explicit connections to high-quality discussions in the classroom. High-quality discussions tend to include higher-cognitive-demand open questions or an appropriate combination of open questions and closed questions, talk moves to be responsive to student talk and to prompt students to extend their responses, and, in the case of science talk, explicit connections to science practices.

As teachers guide classroom discussions and model science talk for their students, the teachers make explicit connections between science practices, such as collecting data and observations and using evidence to justify claims, and the classroom activities in which the students participate to demonstrate to the students that the students engage in the practices of science. There are instances in the SPICE curriculum in which the participating teachers identify the students as scientists as they make predictions, collect data, and justify claims through evidence, which is important for students as newcomers to science practices and to science talk. In the same way, teachers make explicit connections between the classroom talk and the actions of scientists to demonstrate that the students engage in science talk like formally trained scientists (Michaels et al., 2008; Roth, 2002; Windschitl et al., 2018). Within the SPICE curriculum, the teachers model participation in science disciplinary conversations. For example, the teachers explicitly identify the similarities and differences between everyday science talk and more formal, academic science talk (Benedict-Chambers, Kademian, Davis, & Palincsar, 2017; Windschitl et al., 2018) for the students, such as through distinguishing formal vocabulary like "permeability" and everyday understandings like "absorbs the water or the rainfall." Similarly, the teachers explicitly identify instances of high-quality discussion, such as the use of open questions compared to closed questions, to identify the different types of questions that teachers ask but also to make explicit connections between the types of questions and limited or extended student responses (Benedict-Chambers et al., 2017; Michaels et al., 2008). The teachers also identify different student responses to encourage the extended student responses with deeper reasoning, such as noticing when students disagree with other students' calculations or evaluate other students' water runoff models. When the teachers identify teacher questions and student responses that relate to high-quality discussions, the teachers and students have opportunities to reflect on their contributions to the discussion. During the classroom talk, the teachers model high-quality discussion, and the teachers identify opportunities and practices for engagement in high-quality discussion by explicitly connecting the teacher and student talk with indicators of high-quality discussion.

Predominance of teacher-mediated student talk. In alignment with the second and third research sub-questions, the second theme from the findings asserts that the teachers mediate most instances of student talk during the science-focused lessons of the SPICE curriculum. The second theme also asserts that the non-teacher-mediated student talk, though uncommon, typically occurs in conjunction with student participation in curricular activities. A further discussion of the findings, implications, and recommendations related to this second theme follows below.

Teacher-mediated student talk. When looking at the classroom talk of the SPICE curriculum, there are similar proportions of discussion-related teacher talk and discussion-related student talk. This similarity in proportions suggests that teacher questions and talk moves mediate most student talk and that most student talk consists of responses to teacher questions and talk moves rather than student-student talk. However, even if teachers mediate most student talk through teacher questions and talk moves, the students participate in the classroom discussions. One goal of scientific discussions and of the SPICE curriculum is for students to contribute to classroom discussions at their own pace without the teachers' mediation. As newcomers to the practices of science talk, the teachers' mediation guides the students' participation in the classroom discussions (Chin, 2006; Kawalkar & Vijapurkar, 2013) and models engagement in scientific discussion for the students. Therefore, the classroom discussion flows through the teacher, but the mixture of closed questions, open questions, and talk moves elicits student participation in the classroom discussion and engages students through teacher-guided instruction rather than teacher-centered instruction.

Non-teacher-mediated student talk. Although most student talk in the SPICE curriculum occurs in response to teacher questions and talk moves, the instances of non-teacher-mediated student talk demonstrate that students also participate in the classroom discussions outside the mediation of teacher talk. Some instances of non-teacher-mediated student talk include additional responses to teacher questions, questions directed to the teacher, and comments directed to the teacher about questions or the content. These examples of non-teacher-mediated student talk refer to teacher talk or involve the teachers in some way even if the student talk is not a direct response to a teacher question or talk move. However, other instances of non-teacher-mediated student talk include student-student talk. Exploring the context of non-teacher-mediated student talk provides further information on the individual lessons and the parts of the curriculum that are associated with non-teacher-mediated student talk.

Within the individual science-focused lessons, there are similar proportions of overall discussion-related student talk, which suggests that students participate in whole-class discussions at similar proportions in each lesson. For non-teacher-mediated student talk, higher proportions of non-teacher-mediated student talk are associated with lower proportions of teacher questions, talk moves, and teacher-mediated student talk. This association suggests that student talk that does not flow through the teacher occurs more frequently when teachers engage students with fewer teacher questions and talk moves.

In addition to fewer instances of teacher talk, the differences among the individual lessons also suggest opportunities for non-teacher-mediated student talk. The lowest proportion of non-teacher-mediated student talk occurs during Lesson 2, which suggests a difference between Lesson 2 and the other lessons. As previously discussed, the teachers use Lesson 2 to introduce the curricular objective of determining the amount of water runoff and the computer program for designing the students' water runoff models. During the other science-focused lessons, the curricular activities include different investigation activities that explore amount of water absorption and runoff and opportunities for students to revise their water runoff models. The non-teacher-mediated student talk from Lesson 2 occurs as the students develop their initial water runoff models, and the non-teacher-mediated student talk from Lessons 3, 4, and 5 occurs during the set-up, data collection, and data analyses for the investigation activities and during discussions of the student-generated water runoff models that students revise as they develop a deeper conceptual understanding of water runoff through each lesson's investigation activity. These instances of non-teacher-mediated student talk suggest that students typically make connections between their experiences and the curricular activities when they engage in non-teacher-mediated student talk. For example, non-teacher-mediated student talk occurs when students connect their personal experiences to the water runoff design challenge, correct other students' data calculations, and evaluate other students' water runoff models. These hands-on activities serve as anchor points for classroom discussion (Kawalkar & Vijapurkar, 2013; Murphy, 2007; Windschitl et al. 2018) as the students refer to the investigation activities and the student-generated models throughout the unit for content and discussions. When the students engage with an activity, student talk tends to occur more frequently without flowing through teacher questions or talk moves. Therefore, non-teacher-mediated student talk tends to occur in relation to fewer instances of teacher talk and in relation to activities.

Recommendations for non-teacher-mediated student talk. One goal of the SPICE curriculum is for students to engage in classroom discussions directly with other students through student-student talk. As newcomers to science talk, students may be unfamiliar or uncomfortable with scientific discussion. The following section addresses recommendations for teachers to encourage students to engage in student-student talk.

Clear norms and guidelines for classroom discussions. As newcomers to the practice of science talk, the students at BUES are also newcomers to classroom discussions and to student-student talk. For students to engage in student-student talk, teachers establish norms, expectations, and guidelines to create an environment in which students feel safe to present their ideas and to assess other students' ideas, and teachers also provide structures to guide students as they interact with other students' ideas (Edmondson & Choudhry, 2018; Mercer et al., 2004; Shechtman & Knudsen, 2011; Windschitl et al., 2018). These norms and expectations create safe environments for classroom discussion but also emphasize the practices of science. Students pay attention to the classroom discussions, listen to each other, remember prior contributions, and acknowledge previous student talk by building on an existing idea or contributing a new idea. Students are also encouraged to make mistakes during classroom discussions. Ultimately, students are encouraged to participate in the classroom discussions. These norms and expectations emphasize the social nature of science through participation in the classroom discussions and through the development of scientific ideas over time as students act as scientists by building on previous ideas or contributing new ideas.

In addition to norms and expectations, the participating teachers at BUES and teachers in general can provide structures to guide students in their student-student talk. During the enactment of the SPICE curriculum at BUES, many instances of student talk involve only a small number of students from each class section, so some students do not feel comfortable participating in the classroom discussions. Also, some instances of student-student talk involve students interrupting each other, and while this type of talk may be suitable in settings outside the classroom, it may not be conducive to encouraging large numbers of students to participate in student-student talk within classroom discussions. To provide structure and guidance for students to engage in student-student talk, teachers can provide language supports, such as sentence starters (Roth, 2002) or other scaffolded supports (Windschitl et al., 2018). For example, the scaffolded language supports provide options for students to use to build on another student's comment (e.g., "I agree with your idea, but I am also considering…"); to inquire about evidence and reasoning to justify a claim (e.g., "What made you reach that conclusion?"); to look for an idea to be clarified (e.g., "Could you explain that idea further?"); or to disagree politely with another student's idea (e.g., "I understand your reasoning, but I have a different idea."). By displaying these language supports in a common area of the classroom, the teachers can guide student participation in student-student talk, and students can refer to the supports on their own. Therefore, teachers can develop norms, expectations, and guidelines for classroom discussions to guide and support student engagement in student-student talk.

Connections between experiences and classroom discussions. When the students engage in non-teacher-mediated student talk within the SPICE curriculum, they tend to refer to their personal experiences or to their common experiences with the investigation activities. The investigation activities explore the relationships between hourly rainfall rate and rainfall duration, between different types of surface material and amount of rainfall absorption, and between amount of water absorption and amount of water runoff. The investigation activities include multiple opportunities for common experiences among the students, including activity set-up, data collection, data analysis, construction of a scientific argument based on evidence and reasoning, and new content that students use to revise their water runoff models. Both the teachers and the students refer to these common experiences during classroom discussions about content and about revised water runoff models, so the investigation activities serve as anchor points for the classroom discussions (Kawalkar & Vijapurkar, 2013; Murphy, 2007; Windschitl et al., 2018). The participating teachers at BUES utilize these anchor activities within the SPICE curriculum effectively as reference points for classroom discussion because the teachers and students experience the activities together but also because the content explored in the anchor activities builds from lesson to lesson. The teachers use questioning to guide the students as they construct their content understanding during each lesson and as they make connections among the investigation activities and the associated content in different lessons. The teachers of the SPICE curriculum engage students to participate in high-quality student-student talk through setting norms and guidelines for classroom discussions, providing language supports for participation in classroom discussions, and providing anchor activities to which students can refer during classroom discussions.

Teacher talk, elicited student responses, and question sequences. The third and fourth themes from the findings align with the third research sub-question. The third theme asserts that closed teacher questions tend to elicit narrow student responses and that open teacher questions tend to elicit broad student responses. The fourth theme extends this finding and asserts that question sequences group together different proportions of teacher talk-narrow response pairs and teacher talk-broad response pairs depending on different instructional goals. While high-quality discussion typically relates to open questions rather than closed questions, the two types of questions exist together within classroom discussions and complement each other based on the instructional goal. A further discussion of the third and fourth themes and the associated implications and recommendations follows below.

Teacher talk and elicited student responses. Within classroom discussions, the teacher talk elicits different types of student talk. The lower-cognitive-demand closed teacher questions tend to elicit narrow student responses, which align with the elicitation of limited options based in yes/no binary responses, factual recall responses, and responses that refer to previously determined activity set-up procedures or design decisions for the water runoff models. The higher-cognitive-demand open teacher questions tend to elicit broad student responses, which align with the elicitation of multiple options based in students' ideas, predictions and hypotheses, descriptions, and explanations and reasonings. When considering the classroom talk of the SPICE curriculum, there is a higher frequency of closed question-narrow response pairs and a lower frequency of open question-broad response pairs, which suggests that teachers provide students with limited opportunities to participate in extended classroom discussion and that teachers engage in teacher-centered instruction (Cicchelli, 1983; Mercer, 2010). However, the higher frequency of closed question-narrow response pairs does not present a complete representation of the classroom discussion.

In addition to the higher frequency of closed question-narrow response pairs, the participating teachers also use talk moves within the classroom discussion. There is a higher frequency of talk moves that elicit broad responses and a lower frequency of talk moves that elicit narrow responses, and this difference suggests that students elaborate their classroom talk in response to talk moves as well as in response to open questions. The participating teachers employ various types of teacher talk to elicit student responses within the classroom discussion. This balanced approach of lower-cognitive-order closed questions and talk moves eliciting narrow responses and of higher-cognitive-order open questions and talk moves eliciting broad responses suggests that teachers guide the classroom discussion to focus on student thinking and reasoning in addition to correct answers (Chin, 2006), especially within the context of fifth-grade elementary science classes for whom higher levels of teacher guidance (Hogan et al., 1999) may be helpful.

Within these teacher-guided classroom discussions, open questions are typically associated with high-quality discussions because open questions elicit multiple broad response options from students (Oliveira, 2010; Pimentel & McNeill, 2013). Open questions provide a space for students to reflect on their ideas (Michaels et al., 2008) and construct conceptual understandings (Hancock et al., 2002). However, closed questions serve a pedagogical purpose (Ho, 2005) within classroom discussions and at times complement open questions. When students do not respond to initial open or closed teacher questions, the participating teachers tend to adjust by rephrasing the question using a more direct and straightforward closed question. This rephrased closed question typically elicits a student response and allows the classroom discussion to continue. This use of a rephrased closed question to elicit a response from an initial, open question suggests the flexibility of the teachers within classroom discussions and one way that open and closed questions completement each other. Also, the teachers in the SPICE curriculum use closed questions to review and check students' understanding of previously learned content, to review formal scientific vocabulary, and to review set-up, data collection, and data analyses for investigation activities. The participating teachers use these closed questions to establish common experiences with the investigation activities and water runoff models as anchor points for use as references in classroom discussions. The teachers then refer to these common experiences and use open questions to elicit ideas, descriptions, and explanations from students. Therefore, while open questions are typically associated with high-quality discussions, the presence of closed questions within classroom discussions does not detract from the quality of the discussion as closed questions serve a pedagogical purpose in conjunction with the open questions.

Question sequences and instructional goals. Question sequences include groups of teacher talk-narrow response pairs and teacher talk-broad response pairs that together serve a particular instructional goal. In general, a higher proportion of teacher talk-broad response pairs in a question sequence tends to correspond to a lower proportion of teacher talk-narrow response pairs. However, different types of questions are associated with different instructional goals (Benedict-Chambers et al., 2017; Chen, Hand, & Norton-Meier, 2017), and question sequences with different instructional goals include different proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs. As discussed in a previous chapter, some question sequences (i.e., Review, Activity Set-up and Enactment) include higher proportions of teacher talk-narrow response pairs to establish common classroom experiences of previously learned content and of investigation activities for reference in classroom discussions. Other question sequences (i.e., Patterns, Comparing Models, Predictions, Personal Experiences) include higher proportions of teacher talk-broad response pairs to engage students in discussions about their personal experiences or the synthesis of new ideas. Most question sequences (i.e., Defining Terms, Describing Concepts, Data and Observations, Design Challenge, Argumentation) include similar or balanced proportions of teacher talk-narrow response pairs and of teacher talk-broad response pairs. Therefore, different question sequences with different proportions of teacher talk that elicits narrow responses or broad responses are associated with different instructional goals.

Recommendations for planning with question sequences. Curricular and lesson planning are important for teachers to guide student participation in high-quality discussion. Planning for the instructional goals of different kinds of classroom discussions allows the teachers the opportunities to choose tools like questions and talk moves that support the instructional goal and to anticipate and manage the expected types of student response within the classroom discussions (Windschitl et al., 2018). While higher proportions of open questions and lower proportions of closed questions are associated with high-quality discussion, this framework of question sequences provides a different approach to planning for classroom discussions. Rather than trying to increase the frequency of a teacher's use of open questions and decrease the frequency of closed questions, teachers can instead focus on the instructional goal associated with different question sequences. When teachers plan to review previously learned content, they can expect to use a high proportion of closed questions so that students can establish a common understanding of concepts and terms. When teachers instead plan for students to make connections to their personal experiences or for students to analyze and synthesize data to develop patterns, they can expect to use a high proportion of open questions and talk moves so that students can elaborate on their responses and develop their reasonings. Teachers can plan to utilize question sequences with different instructional goals so that students can experience a variety of types of questions and talk moves within a lesson. Planning according to instructional goal rather than according to frequency of open and closed questions can help teachers engage students in high-quality discussion that is responsive to student talk and that prompts students to participate in classroom discussions within the context of a lesson, a unit, or an entire curriculum. Therefore, determining instructional goals can guide the types of teacher talk that teachers utilize and the types of student responses that the teacher talk tends to elicit.

Limitations

Within the proposed capstone study, certain limitations are present. First, the data source (i.e., audio recordings) has already been collected. Since the data sources have already been collected, the analyses do not iteratively influence the data collection. In other words, if analyses yield one potential finding, no further data could be collected to support or refute that finding. Instead, all analyses depend on the secondary data sources of the audio recordings. Second, the archival data sources are all collected by other researchers. I did not spend time in the field for this research study. If any questions about data collection arose, I relied on the accounts of other researchers. However, the primary data sources are the text transcripts of the audio recordings of the whole-class discussions, so I can generate my own secondary observational notes if necessary. Third, the study participants are limited to the classroom teacher, the STEM specialist, and the students in the two fifth-grade classrooms participating in the larger SPICE research study. While generalizability is not the goal of interpretive qualitative research, studying two classrooms within a single school in one district can limit the transferability of the findings. However, even if the findings are not transferable to other contexts, studying fewer participants generally allows for deeper analysis. Fourth, during the course of the analysis, using only the text transcripts with some supplemental information from the audio files is limiting. Further analyses should include analysis of the video observations and actual in-class observations to understand any non-verbal cues and to understand the teachers' tendencies since extended time in the field is recommended with case studies and with qualitative work in general (Rossman & Rallis, 2017). Additional analyses could also address the classroom discussion within the small groups. Fifth, due to time constraints, I am not able to conduct member-checking with the two teachers, so I rely on my critical colleagues to reflect on the data and on the credibility of the findings.

Reflection

While this study focuses on better understanding teacher questioning and student responses and the different roles that questions can play within the classroom discussion, this study is prompted by my interest in communication and in relating to one another to better understand each other's experiences. Through better understanding of each other's experiences, individuals, such as students in the classroom, may be more open to participating in classroom discussions. Through this capstone study, I align my research and educational interests in a way that is practical as well as methodologically rigorous. As an educator, using research to support practice is important, and through engaging in this capstone study I can reflect on my past experiences in teaching to see where I could change or update my pedagogy, especially in terms of this study's findings. This capstone experience is an opportunity to dig deeply into research that is meaningful to me while also seeing the direct connections that research can make to practice. Too often, I fail to see how research can be applied to practice, so I am pleased to know that I have been mistaken many times. I look forward to continuing to connect research and practice in my future academic and educational pursuits.

Chapter Summary

In this chapter, I consider the problem of practice regarding the limited participation of students in classroom discussion in one school district and specifically in two classrooms through the lens of classroom talk and high-quality discussion within a community of practice based in the SPICE curriculum in which the students are newcomers to science practice and the teachers are experts in science practice. Then, I discuss the findings and make connections to practical and research implications. I discuss the relationship between teacher questioning and the elicited student responses, with the teacher questions guiding and serving as a model for students' participation in science talk. I discuss the types of teacher talk and the corresponding alignment of the elicited student responses as well as the scenarios in which students engage in student-student talk that is not mediated by teacher talk. I also discuss the groupings of different teacher talk-student response pairs according to similar instructional goals. Throughout the discussion, I present recommendations for the SPICE curriculum and for the teachers as they continue to engage students to participate in classroom discussion. These recommendations include curricular supports for teachers to engage students in high-quality discussions, guidelines and language supports for students to engage in whole-class discussion and in student-student talk, and planning supports for teachers to consider instructional goals in conjunction with planned question sequences within lessons. Finally, I conclude the chapter with a discussion of limitations of the capstone research study and a reflection of the capstone research experience.

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APPENDICES

Appendix A: Provisional Coding Lists

Table A.1

Provisional Codes Applied and Their Definitions

Level 1	Level 2	Code Definition
Teacher Talk	Telling	Teacher providing information about how to do something that is specific to the curriculum
	Asking Questions	Teacher asking questions that may elicit or scaffold student thinking
	Responding to Students	Teacher responding to a student idea by repeating the idea without adding information
		Teacher guiding student thinking toward a response or remarking on the accuracy of student ideas
	Logistics	Teacher managing the discussion (i.e., calling on students, giving non-curriculum related directions to manage behavior)
Student Talk	Contributions to the conversation by students	

Appendix B: Descriptive Coding List

Table B.1
Descriptive Codes Applied and Their Definitions

Level 1	Level 2	Code Definition
Teacher Questions	Closed- yes/no	Question with responses that are limited to yes or no responses; Includes check for understanding (e.g., “Does this make sense?”) (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004)
	Closed- factual recall	Question with responses that are limited to recalling factual or procedural information (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004)
	Closed- design decisions; activity set-up	Questions with responses that are limited to design decisions or activity set-up
	Open- ideas	Questions with multiple possible responses, such as eliciting ideas (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004)
	Open- description	Questions with multiple possible responses, such as describing observations and data (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004)
	Open- explanation/ reasoning	Questions with multiple possible responses, such as constructing explanations (Martin & Hand, 2009; Smith & Hackling, 2016; Yip, 2004)
	Open- prediction/ hypothesis	Questions with multiple possible responses, such as making predictions about what may happen next in an activity (Chin, 2006; Smith & Hackling, 2016)

Teacher Talk Moves	Evaluating	Teacher evaluates the student's response as correct (positive) or incorrect (negative) (Smith & Hackling, 2016)
	Acknowledging	Teacher recognizes or accepts a student's response without positively or negatively evaluating the response (Smith & Hackling, 2016; Tytler & Aranda, 2015)
	Pressing	Teacher asks a student to elaborate on an idea, add to an explanation, provide further evidence, or present ideas, observations, or personal experiences (Smith & Hackling, 2016; Tytler & Aranda, 2015; Windschitl et al., 2018)
	Following up	Teacher asks a question that centers on a student's idea or providing scaffolded cues to assist a student in creating a response (Smith & Hackling, 2016; Windschitl et al., 2018)
	Restating	Teacher restates the student's response or the teacher asks the student to restate the student's response (Smith & Hackling, 2018)
	Revoicing	Teacher identifies the importance of all or part of a student's idea, such as by rephrasing the student's idea or connecting the idea to academic language (Tytler & Aranda, 2015; Windschitl et al., 2018)
	Focusing	Teacher asks students about a part of a complex procedure, representation, or model (Windschitl et al., 2018)
	Rephrasing the question	Teacher re-frames the question, asks the question again with different words, or asks the question with a contextual example (Smith & Hackling, 2016; Tytler & Aranda, 2015; Windschitl et al., 2018)
	Nominating	Nominating a student or calling on a student to answer a question that has typically already been answered; a student often has already responded, and the teacher calls on another student to provide another response
	Response to question	Teacher responds to a student-generated question
	Prior Knowledge	Associated with the lead-up to the initial question of a question sequence; the teacher generally provides information that activates students' prior knowledge
	Providing background information	Teacher provides background information that is useful to students for participating in the discussion or for conducting the activity
	Providing content information	Teacher provides content information or direct instruction that supports the students as they participate in the discussion or conduct an activity

Student Responses	Narrow- yes/no	Responses that are limited to yes or no responses; Includes responses to checks for understanding (Chin, 2006; Smith & Hackling, 2016)
	Narrow- factual recall	Responses that are limited to recalling factual or procedural information (Chin, 2006; Smith & Hackling, 2016)
	Narrow- design decisions; activity set-up	Responses that are limited to design decisions or activity set-up (Chin, 2006; Smith & Hackling, 2016)
	Broad- description	Responses in which students describe or depict current or previous observations of objects or events (Smith & Hackling, 2016)
	Broad- ideas	Responses in which students offer ideas (Chin, 2006; Smith & Hackling, 2016)
	Broad- explanation/ reasoning	Responses in which students explain or clarify an idea or process or in which students provide a scientific reason or evidence to justify a claim, explanation, or argument (Chin, 2006; Smith & Hackling, 2016)
	Open- prediction/ hypothesis	Responses in which students make predictions about what may happen next, such as in an activity (Chin, 2006; Smith & Hackling, 2016)
	Other- reply	Response in which one student responds to another student; the reply could be further classified as a closed response or as an open response (Chin, 2006)
	Question	Student asks the teacher a question, generally as a follow-up to another question or idea or as a way to clarify a concept or activity