DESIGNING FOR SCIENCE TALK AT HOME

by

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Abstract

Science talk is central to learning in the classroom but despite a variety of interventions, lack of participation in discussion is a persistent obstacle to learner engagement (Clarke, 2015; Mercer, 1996; Mercer et al., 1999; Webb, 1989). Classroom programs may aid student participation but have not been sufficient to overcome students' unwillingness to participate (Hogan, 1999; Olitsky, 2007; Wiltse, 2006). In this design-based research intervention study, guidance in the form of instruction, training, and scaffolds were iteratively designed to facilitate productive scientific discourse between sixth-grade science students and their parents. The main sources of data were recordings of 21 homework assignments during which parents prompted students to evaluate models based on evidence. The features of the intervention were examined using qualitative and quantitative methods. Suggested prompts for parents and a scaffold for model-evidence coordination (based on the work of Rinehart et al., 2014) were responsible for most students making connections between the evidence and one or more of the models. Parents used the suggested prompts and many of them took an active approach by elaborating on the suggested prompts. These parent-initiated questions outside of the suggested questions and materials resulted in more students giving high-quality responses that explained why a model was either a good fit or one that should be ruled out. The results demonstrate that with guidance, parents helped students engage in scientific discourse. The implications of these interactions on student learning are discussed. The findings may be used for future family engagement programs and interventions to build student understanding through talk.

Keywords: family engagement, homework, middle school, modeling, scaffolds, science

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I dedicate this dissertation to my daughters, who inspire me and give me hope to pursue a more just world. May you be forever curious, courageous, and wise.

> *"*I am convinced that every effort must be made in childhood to teach the young to use their own minds. For one thing is sure: If they don't make up their minds, someone will do it for them.*"* – Eleanor Roosevelt

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CHAPTER 1: INTRODUCTION

It's the "middle" that matters. Through these critical years, children, age eleven at grade six, develop into adolescents and are expected to master a rigorous curriculum. One challenge is that science discourse, a prominent component of middle school science, consists of unwritten rules about how to propose, explain, agree, and disagree with evidence. Such talk is conducive to deepening explanations and building knowledge but requires instruction, practice, and reinforcement. In this intervention, parents are given suggested questions about scientific models and evidence to engage in a discussion with their children. This study was designed to facilitate interactions between parents and children that support science learning and addresses our need to understand how learning happens in real-world settings.

Statement of the Problem

In middle school science, students are expected to participate in classroom talk in both whole-class and small groups. Classroom talk as a pedagogical strategy is grounded in a socio-cultural approach to learning (Vygotsky, 1978). It is in wide use in classrooms in this state and in schools across the nation, as evidenced by the adoption of standards such as The New Jersey Student Learning Standards (NJSLS) for English Language Arts (Anchor Standards for Speaking and Listening) and Mathematics (Mathematical Practice: Construct viable arguments and critique the reasoning of others) (NJ Department of Education, 2016). The Next Generation Science Standards (NGSS Lead States, 2013) identify scientific discourse as a central practice for disciplinary learning. These approaches are also known as dialogue-intensive or talk-intensive pedagogies, dialogic pedagogy or classroom dialogue.

The rationale behind these approaches is that more student talk in the form of academic discourse results in more learning for all students (Resnick et al., 2015). For example, in a study of teacher-student talk, extensive student participation was positively associated with curriculum mastery (Howe et al., 2019). The mechanism behind this learning, as explained by Vygotsky (1981), is that external social interaction develops higher cognitive processes that are internalized within the child's own mind.

The challenge of teaching through dialog is that the development of discourse skills comes differently to different students. Their participation depends on gender, ethnicity, academic achievement and other factors therefore students do not participate equally and learning benefits are unevenly distributed (Howe & Abedin, 2013). Despite a variety of interventions, lack of participation in discussion is a persistent obstacle to learner engagement (Clarke, 2015; Mercer, 1996; Mercer et al., 1999; Webb, 1989). School-based interventions show promise but may not be enough to overcome students' unwillingness to participate (Hogan, 1999; Olitsky, 2007; Wiltse, 2006).

Meanwhile, parents are a powerful source of support for student achievement (Axford et al., 2019; Henderson & Mapp, 2002). Parents who may be accustomed to school-based involvement in elementary schools find there are fewer opportunities to be present in middle schools. Family engagement is nonetheless valuable, even as the needs and responsibilities of parents as educational partners changes as children get older. Instead of school-based activities, home-based involvement may help students academically by conveying the value of education. Family participation in school-related activities, especially those that foster academic attitudes, ideas, and behaviors and perceptions of competence, can positively influence student outcomes (Fan & Chen, 2001, Hill & Tyson, 2009; Hoover-Dempsey & Sandler, 1995, Steinberg et al., 1992).

Researchers have prepared activities to involve parents in homework and other academic activities (Heddy & Sinatra, 2017). Interventions with parents have the potential to be helpful, but complex personal and family dynamics and contradictory social-emotional and academic goals may overwhelm learning goals. Parent involvement in homework help has had mixed results and those results do not establish a line of causality from the help to achievement (Cooper et al., 2000; Georgiou, 1999). Parents are not trained tutors, and their assistance may not help student performance and sometimes may be a detriment (Hill & Tyson, 2009, Lee & Bowen, 2006). Assistance in the form of "homework help" is often counterproductive. For example, in a study of arithmetic word problems, parents tended to provide much more direct forms of assistance than did teachers and few gave justifications (Lehrer & Shumow, 1997). In other instances, parents take over the cognitively difficult tasks (Gleason & Schauble, 1999) rather than support children's independent work, resulting in a lost learning opportunity. Other approaches to parent involvement that can help students solve problems independently have been promoted. Oral communication is prominent in these recommendations (Heddy & Sinatra, 2017)

Parent-child discussions might have a positive influence on student academic achievement in a number of ways. These discussions might help students complete homework directly by answering questions or indirectly by supplying a reminder. They might remind students what they learned at school, or they might give students the impression that parents value school or academic achievement and promote interest and motivation. It is critical however to communicate to families that their involvement is not just welcome but encouraged and to offer strategic ways that adults can be helpful to students' academic achievement (Halsey, 2005).

Purpose of the Study

The purpose of this study was to understand and support parent-child interactions in the context of scientific inquiry. I employed design-based research methods to study the design and implementation of the intervention in order to explain how learning might occur in this setting (Design-Based Research Collective, 2003). Beyond finding practices that are effective in complex, real-world settings, design experiments are extended (iterative), interventionist (innovative and design-based) and address the learning ecology, the interactions between the tasks or problems that students are asked to solve, the kinds of discourse that are encouraged, the norms of participation that are established, the tools and related materials. Though the theoretical framework of a design experiment may be “humble” in that it may target domain-specific learning processes, a design study explains why designs work and suggests how they may be adapted to new circumstances, making them pragmatic as well as theoretical (Cobb et al., 2003).

In design-based research, argumentative grammar in the form of a conjecture map is used to articulate a theoretical framework for the design of features, anticipated mediating processes and expected outcomes (Sandoval, 2004, 2014). Generally, the initial design is a hypothesis about how participants interact with the tools and materials, participation structures and activity structures of the intervention to lead to learning. Through iterative design changes to those features more specialized conjectures are developed and tested. The observable interactions between participants and their artifacts are carefully analyzed to understand how the mediating processes support the learning outcomes (Sandoval, 2014).

The initial conjecture map for this study included an array of possibly significant tools and materials, a general involvement by parents, and undefined learning talk as the outcome. As the design features were implemented and analyzed, more specific pathways and interdependent processes were identified, as shown in Figure 1.

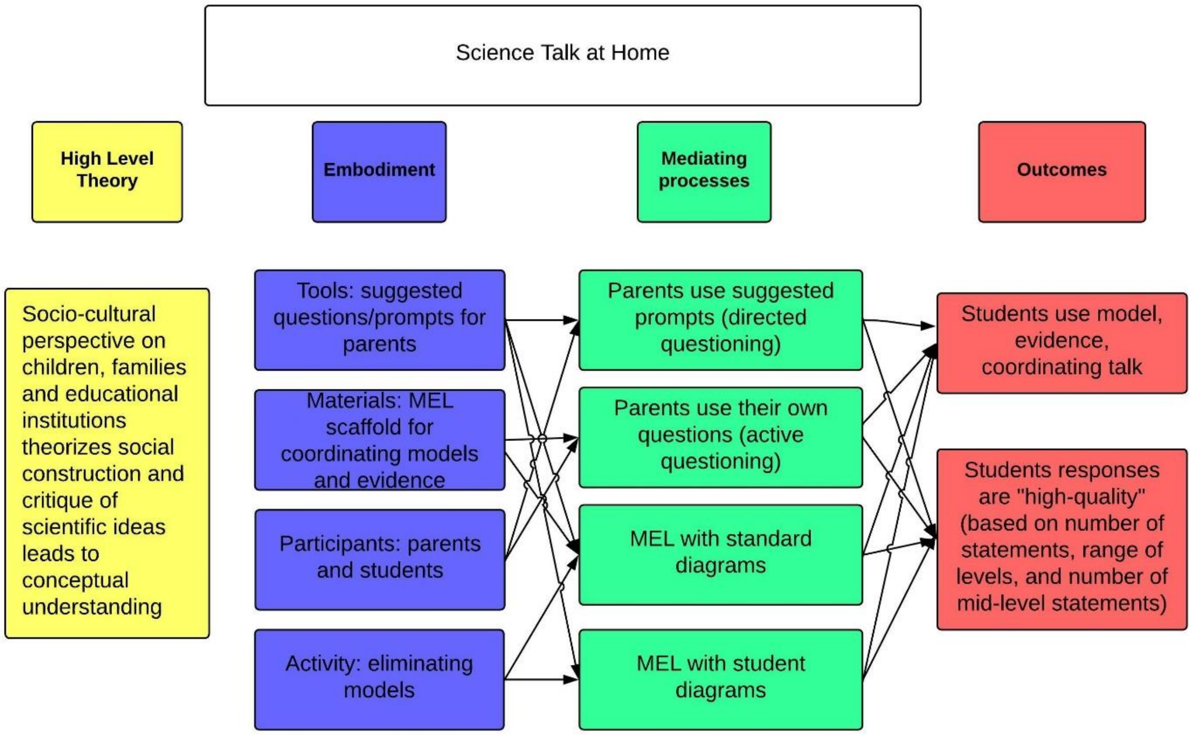


Figure 1. Embodied Conjecture

Throughout this study, the conjecture map guided the enactment of the intervention and the collection and analysis of data. The argumentative grammar of the conjecture map provided a reference to explain how the mediating processes contributed to the observed outcomes. In the sections below I outline the components of the intervention: the high level theory, the critical features of the embodiment, the mediating processes and the expected outcomes. In subsequent chapters I describe each in more detail.

High Level Theory. As discussed in the introduction, this study evolved from a socio-cultural perspective on children, families and educational institutions. Vygotsky's idea that much of children's cognitive development occurs through social interaction is an underlying principle of science curriculum. Though ideas about dialogic pedagogy, or talk as an essential part of learning, are complex and contentious (Asterhan et al., 2020), they have in common a grounding that the social construction and critique of scientific ideas leads to conceptual understanding. Sociocultural approaches to science learning take the view that practice with generating and debating ideas results in the development of scientific understanding. The development is shaped by students' personal experiences and their interactions with the ideas of others (peers and teachers) (Berland & McNeill, 2010; Osborne, 2010).

Embodiment. The conjecture is embodied in the features of the intervention. Below I outline the tools and materials, participants, and the activity.

Tools. The tools for parents were designed as "guidance" to support their participation in the activity. The first resource was a video introduction focusing on the power of parent engagement and the purpose of the study. A two-minute instructional video called "how to" outlined the task and offered suggested prompts. The suggested prompts were also provided in a reference booklet, sent home on paper and electronically.

The suggested questions were provided due to possibility that in the absence of suggested questions, parents might use "test questions," those that have a particular correct answer and which would not encourage high-level thinking (Wei, et al., 2018; Wei & Murphy, 2017). The suggested questions were requests for generalization or analysis, questions that required students to consider other possibilities, and requests for justifications. In the Quality Talk program, a teacher-facilitated, small-group discussion approach designed to enhance students' comprehension program, these types of talk moves are categorized as "prompts," "speculation," or "challenges," respectively (Murphy et al., 2018).

The questions on the reference sheet were developed, tested and refined over the course of the year as through teacher-led classroom discussion, through pilot study, and with other teachers. Results from the responses from students in the first two classes led to further revision for the second set of two classes. The prompts specifically referred to aspects of the Model-Evidence-Link matrix. In Chapter 2, I describe in more detail the rationale behind the development of the prompts.

Materials. Student materials included the Model Evidence Link (MEL) matrix used to coordinate models and evidence (Rinehart et al., 2014). Keep tracking of evidence, using evidence to evaluate models and constructing oral and written explanations based on evidence are cognitively challenging activities. The MEL was used as a scaffold to support these activities. Scaffolding is the process by which a teacher or more knowledgeable peer helps a learner succeed in a task or problem that would otherwise be out of reach by modifying the learning task (Collins et al., 1989; Wood et al., 1976, as cited by Reiser, 2004). Two important functions of scaffolds are to facilitate articulation and make epistemic characteristics of the product explicit (Quintana et al., 2004). In this case, the product was the selection of an explanatory model from among several alternatives. The students use the MEL refer to the evidence to justify their choice. I describe in detail how the MEL was created in classroom activities with students in Chapter 3.

Participants. The involvement of parents was a critical design feature supported by family engagement research. Parents might act as facilitators, using questions to encourage talk about models and evidence, or as instructors or evaluators, if the topic was familiar, or as novices, asking authentic questions to understand. Children respond to their parents in their role as students.

Activity. The activity was centered on students evaluating the strength of the body of evidence and its connection to their chosen model. They were instructed to pay attention to how the evidence allows them to "rule out" one of the proposed models. Students eliminated an explanatory model from among several viable options and justified their choice using disciplinary norms for evidence (Duschl & Osborne, 2002). The activity was embedded in a program of science instruction that included extensive work with models, argumentation, and scientific discourse, consistently practiced in different topics and in different formats throughout the school year.

Mediating Processes. The tools and materials, participation structures, and activities were designed to promote familiar patterns of interactions, asking questions and offering explanations. Two mediating processes were analyzed for their impact on the outcome measures: the use of questions by parents and the design of the MEL.

Parents were encouraged to use the prompts that are specifically related to the science topic to stimulate student science talk. Parents used the suggested questions such as "why did you eliminate this model?" and "what would you say if…?" Parents also asked different questions, repeated student ideas and asked students about other ideas, terms or concepts. The intention of the prompts was to scaffold parents questioning and extend the discussion in order to promote talk about models and evidence.

There were two iterations of the MEL and there were differences in how two versions of the MEL were used. The first one had standard line drawings as models and the second one had student-drawn diagrams. Based on differences between the responses, the differences in the MEL matrix mediated the quality of response.

In addition, interactions between these two mediated processes (the parent use of questions and the design of the MEL) were analyzed for their combined contribution to differences in the outcome measures.

Outcomes. Two outcomes of the intervention were measured: the amount and frequency of student talk about models and evidence on the MEL and the quality of the student response. These outcomes were measured by the collection and analysis of statements recorded and submitted by the students as their homework assignment. Multiple analyses were conducted and are described in Chapter 4. The analysis of student talk was conducted to determine associations with the two forms of the MEL. All of the statements by each student were evaluated as whole explanation and the inclusion of statements that connected the models and evidence and justified the connections was used as an indicator of a high-quality response. Variations in parent questioning approaches were analyzed to find an association to the quality of student explanations. Some high-quality responses with active questioning by parents demonstrated productive scientific discourse. Interactions such as the ones facilitated by the features of the intervention were expected to aid learning based on dialectical argumentation research (Asterhan & Schwarz, 2009).

Research Questions

The first research question focuses on the links between the tools and materials (instruction, training, scaffolds) and the mediating processes. The second research question addresses the connection between the mediating processes and the learning outcomes.

The research questions guiding this study were:

- What are the features of the guidance (instruction, training, and scaffolds) that facilitate parent-child interactions?

- What talk moves by parents and children are associated with more productive discourse?

The study examines the use of teacher-provided guidance (instruction, training, and scaffolds) in order to determine how they facilitated parent-child interactions and what characteristics of those interactions are associated with productive discourse. It is organized around the premise that science discourse is conducive to deepening explanations and building knowledge but requires instruction, practice, and reinforcement. In the following chapter I describe in detail the theoretical bases for this premise.

The procedure for implementing the intervention and collecting and analyzing data is described in Chapter 3. Parents were enlisted to practice learning talk with students and were offered guidance with training and scaffolds. Students were instructed to evaluate the strength of the body of evidence and its connection to several plausible models using a Model-Evidence-Link (MEL) matrix scaffold that was created through classwork. The development of these two critical features and how they differ in the two iterations are explained.

Chapter 4 focuses on the findings from the observed interactions between participants and the tools and materials in order to understand the mediating processes of the intervention. Using the argumentative grammar from the conjecture map, I show how the features of the intervention contributed to the outcomes. Differences in the patterns of parent-child interactions are identified and related to differences in the guidance. The suggested questions and the MEL, the participation of parents and students, and the instructions to eliminate models helped students to engage in model, evidence, and coordinating talk. I define high-quality responses to characterize productive discourse in this context.

In Chapter 5 I discuss the findings from this study and how they may be used to inform family engagement interventions, as well as further research on productive discourse, an essential component of science education. I offer reflections on the intervention that might be useful to future researchers.

CHAPTER 2: LITERATURE REVIEW

This chapter argues for a school science intervention to improve student learning by promoting scientific discourse about model building. The first section defines the terms for learning through talk, explains how such learning is supported in schools and homes, and presents the goals and methods for promoting explanatory scientific discourse. The second section makes the case for model building as a focus for science learning talk.

Learning Talk

Learning talk is referred to by numerous terms, generally implying some social interaction and an anticipation of or a response to an idea. One term, "academic discourse," is defined by Mehan and Cazden (2015, p. 20) as "the genre in which ideas are presented (in written or oral form) in academic or scholarly context that privilege the analytical and the presentation of evidence to advance an argument (Toulmin, 1958)." This definition incorporates the use of evidence to support an argument, consistent with another term, "argumentation," the process of thinking and social interaction in which individuals support claims with evidence and premises (Golanics & Nussbaum, 2008). "Critical elaborative discourse," the term used by Nussbaum (2008), delineates the activity when participants assume different points of view and use arguments, counterarguments, and refutations to resolve their conflicting opinions. As there is overlap between these terms, I refer to the activities as "learning talk" when there is general discourse in which participants talk with the goal of deepening understandings about ideas. I use the terms "academic discourse" or "argumentation" when the participants request or use evidence to support their claims for the purpose of sharing or building knowledge regardless of the academic domain. I use the term "scientific discourse" to refer to activities in which students support claims about scientific ideas with evidence from observations, demonstrations, experiments or texts to support their reasoning. This scientific discourse is enhanced when participants use justifications, rebuttals, and counterarguments. The four types of learning talk and their characteristics are shown as tiers in Figure 2.

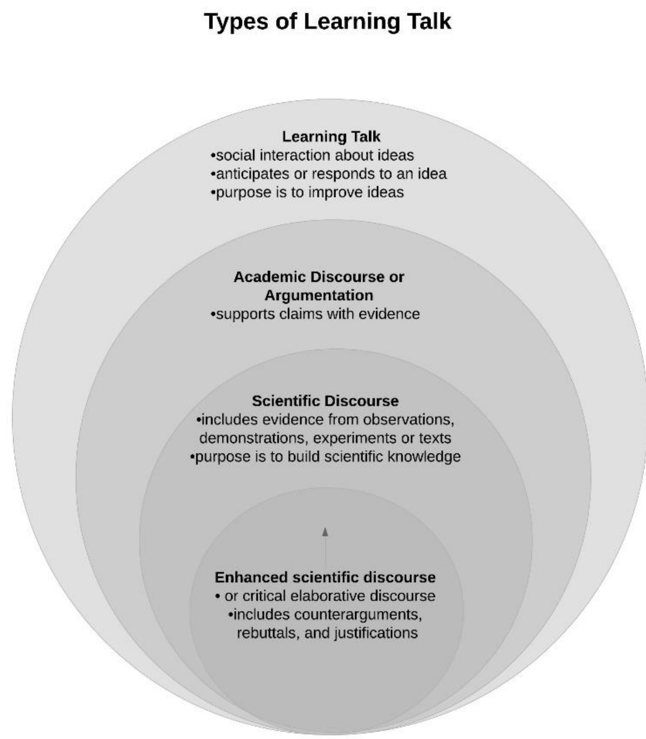


Figure 2. Types of Learning Talk

The kind of talk students engage in is important for cognition (Asterhan & Schwarz, 2009; Mehan & Cazden, 2015; Resnick et al., 2015). Student participation in learning talk may lead to robust learning for more students than traditional teacher-directed talk. The learning outcome of interest is students demonstrating an understanding of conceptual content knowledge. The traditional teacher-directed talk, now well-known as Initiation-Response-Evaluation, was described by Mehan (1979) in a classroom study during the 1974-75 school year. In a traditional classroom context, teachers utter 50% to 70% of all the words spoken (Cazden, 2001), leaving students without the opportunity to learn from each other. Other classroom contexts, such as those designed around Collaborative Reasoning discussions, can induce more student talking (Chinn et al., 2001; Murphy et al., 2009). Compared to baseline discussions in the same classrooms, the talk during Collaborative Reasoning includes a significantly higher rate of providing explanations, elaborating ideas by linking them to prior knowledge, drawing inferences that connect different parts of texts, and supporting ideas with text evidence (Chinn, et al., 2001; Murphy, et al., 2009).

Learning Through Talk. More student talk in the form of academic discourse results in more learning for all students (Resnick et al., 2015). Classrooms where students explain their ideas in detail and invoke evidence to support their reasoning are believed to help learning by making thinking explicit and exposing thinking to critique and improvement. Academic discourse increases cognitive demand by asking students to defend their statements, thereby building more complex knowledge (Mehan & Cazden, 2015). Content understanding from student collaborative discourse may develop through (a) sociocognitive conflict, and (b) cognitive elaboration (Nussbaum, 2008). Similarly, Chinn and Clark (2013) identify three factors that promote content learning: elaborative processing, learning from others, and reason to believe. Cognitive elaboration is the process through which learners make connections to prior knowledge and between concepts. The learner’s need to be understood by others and to understand the ideas of others, in other words, socially-constructed knowledge, may be identified as “collaborative reasoning.”

The mechanism of cognitive elaboration or elaborative processing is supported by research that shows having students give explanations is more predictive of learning gains than receiving explanations or giving simple answers (Webb et al., 2008). Giving explanations may facilitate learners making connections to prior knowledge and between concepts. There is evidence that students may not need to have a partner to learn from explanation. In some contexts, students may learn from giving explanations (self-explaining) to themselves (Chi et al., 1994). The studies asked students to explain what they learned from reading a text or explain how they solved a problem. Explanatory talk by individuals or groups of individuals is cognitively beneficial because it externalizes knowledge or understandings.

Once ideas are externalized, the social mechanism of learning from others enhances cognition. This conclusion is supported by research that explores the learning of students working in pairs or groups (Asterhan & Schwarz, 2009; Hogan et al., 1999). The goal of explaining focuses the social interaction on learning from others. Students must listen carefully and respectfully and evaluate their own and competing ideas. Collaborative work in which students working together to build a consensual explanation or engage in elaboration-based activities show learning gains under certain conditions (Asterhan & Schwarz, 2009). More sophisticated reasoning can result from students working in groups using connected discourse to elaborate on one another's ideas (Hogan et al., 1999). This contributes to students engaging in a higher level of evaluative cognition.

To summarize, learning environments in which students participate in scientific discourse support cognitive growth. Observational studies of skilled teachers leading small group discussions, (e.g., Hogan et al., 1999) give researchers ideas about how to set up classrooms environments that promote productive academic discourse. It is expected that some form of instruction is also necessary, because students arrive at school with different dispositions towards and proficiencies in such talk. The instruction may be guided by considering students' prior experience with learning talk with their first teachers, their parents.

Socializing Learning Talk at Home. The importance of family talk as a stimulator of young children's language learning is undisputed (Boland et al., 2003; Heller, 2014. Studies conducted in informal learning settings, such as museums and science centers, show that parent-child interactions spontaneously produce extended explanatory discourse (Fender & Crowley, 2007; Szechter & Carey, 2009; Tscholl & Lindgren, 2016). They show how parent-child interactions, stimulated by an engaging science activity, produce science learning talk and demonstrate that parents may be an under-utilized resource to develop skills in academic discourse.

Parents use a variety of conversational techniques to help children learn from science demonstrations, exhibits or activities. Parents use questions that encourage children to focus, to compare, to complete an action, to measure, to infer, to problem solve (Kay & Lundeen, 2010). They also describe evidence, give direction, provide explanation, make connections, and elicit predictions (Szechter & Carey, 2009). Parent explanations can help children understand the function of a novel object (Fender & Crowley, 2007). Parents also offer metacognitive support to children and prompt children to plan, think ahead, and reflect, especially when the activity allows for multiple trials (Tscholl & Lindgren, 2016). All of these strategies engage children in learning talk, which encompasses simple and complex inferences and often provides an explanation or abstract description of an observation. The observations in informal learning settings are brief and do not show how learning talk can be cultivated and developed, but they do provide insight into how parents and children might engage in learning talk that serves as a good foundation for science discourse in school.

Other studies show how patterns of discourse between adults and children impact subsequent activity by children at home and in school. Some interventions show that parents can be trained to prompt children and improve their language skills. Boland et al., (2003) offered training to mothers of four-year-old children in four specific conversational techniques (wh-questions, associations, follow-ins, and positive evaluation) and found that the mothers used the techniques in which they had been trained and that the training had substantial effects on children's language. Children of trained mothers recalled more embellished details than did children of untrained mothers (Boland, et al., 2003). Tscholl and Lindgren (2016) gave conversational scaffolds to adults as their children experienced an interactive exhibit. When the adults perceived that children were engaged, they posed and answered questions to support their children's learning. Parents offered metacognitive support to children and prompted children to plan, think ahead, and reflect. These actions can help children build understanding and support science learning (Tscholl & Lindgren, 2016).

Not all students experience learning talk at home (Heller, 2014). Offering parents training to practice academic discourse in interactions with their children may be effective. However, a synthesis of studies reporting on effective strategies to connect schools, families, and communities recommends fostering rather general actions or attitudes rather than specifics (Henderson & Mapp, 2002). Successful parent involvement programs are driven by a focus on improved student learning and a belief that all parents can support their children's academic success (Henderson & Mapp, 2002). The report recommended that parent involvement programs support parents in teaching their children the importance of education, finding out what their children are expected to know, reinforcing lessons at home, and sending their children to school ready to learn every day.

These recommendations are cautious because the research on parent involvement in school activities does not unequivocally demonstrate beneficial results (Fan & Chen, 2001).

Positive outcomes depend on type of task, structures, and school and family context. In a meta-analysis of fifty studies, parental involvement in school activities was positively associated with achievement, with the exception of parental help with homework (Hill & Tyson, 2009). Some researchers suggest that parent involvement in academic activities is beneficial not because of a direct link to learning outcomes, but because of improved perceptions of competence, attitudes, ideas, and academically positive behaviors (Hoover-Dempsey & Sandler, 1995). When parents engage in modeling, reinforcement, and instruction activities, they reinforce an orientation towards academics. Involvement in these activities has been shown to positively influence student outcomes, in particular for children in early adolescence (Hill & Tyson, 2009; Hoover-Dempsey & Sandler, 1995).

Engaging parents and students in scientific discourse at home will set the stage for student participation in discussion at school. Parents can be supportive partners for this special kind of discourse if they are made aware of its powerful effect on learning outcomes and prepared with scaffolds to initiate and sustain the discourse. In the next section I explain how we expect scientific discourse to proceed in the classroom and demonstrate how academic talk and family conversation at home are mutually reinforced.

Academic Discourse in Science Classrooms. Studies on social knowledge building have helped researchers understand what conditions make it productive and how these conditions are constructed. Elaborated talk in which people explore ideas with the goal of learning is academic discourse. The specific type of talk that has been shown to lead to greater conceptual understanding is known as collaborative argumentation (Asterhan & Schwarz, 2009). Collaborative argumentation is the process of social interaction and thinking in which individuals support claims with evidence and premises (Golanics & Nussbaum, 2008). It stems from the learning theory that language, used by people to grapple with externalized ideas, enables the construction of individual knowledge.

Argumentation is not often seen in science classrooms (Newton et al., 1999). Reluctant teachers and students may be the cause, but the result is that few students have the chance to learn how to engage in discourse with claims and evidence and justifications. In the course of their ongoing research, Mehan and Cazden have determined that "academic discourse is a special genre. No one is a native speaker. Some students have gained familiarity with certain aspects of it…but it is not a completely natural way of speaking for any student" (Mehan & Cazden, 2015, p. 20). There is a need to encourage students to learn the skill, with teachers supporting its practice until it becomes productive.

Without instruction, the discussions that do take place are often comprised of unsupported ideas which leave students unable to track the strength of a claim (Resnick et al., 2015). In addition, many students are left out of the discussion (Webb et al., 2008). Some approaches to teach students to participate in academic discourse have arisen from classroom and experimental studies. Asterhan and Schwarz (2009) used metacognitive prompts to induce more students to examine arguments and counterarguments. Other studies have shown that questioning techniques by students in groups are effective at sustaining elaborative discourse (Chin & Osborne, 2010; King, 1992). King (1992) studied the effect of learning from lectures after giving student generic question stems and examples of how to use such stems to pose questions to themselves and their study partners. In Chin and Osbourne's classroom study, when students brainstormed their own questions, they became aware of gaps in their collective understanding. In the subsequent discussion, they verbalized their beliefs, claims, and misconceptions. Their peers responded by formulating objections and counter arguments, questioning claims and critiquing reasoning. The questions initiated the process of identifying salient concepts to evaluate the correctness of claims (Chin & Osborne, 2010).

The role of teachers as discussion leaders has also contributed some understanding of how students learn to participate in academic discourse. In the classroom studied by Hogan, Nastasi, and Pressley (1999), teacher-guided discussion was a more efficient way of attaining higher levels of reasoning and higher quality explanations as students developed a mental model of the nature of matter. In this classroom, teachers prompted students to expand and clarify their thinking without providing direct information. When students were on their own, their talk was more exploratory and wide-ranging, but some groups elicited elaborations and justifications and persevered to attain higher levels of reasoning. The teachers' discussion questions may have modeled to students an effective process for constructing an explanation. Webb, et al. (2008) studied three math classrooms and found that in the classroom with the greatest amount of correct and complete student explaining, the teacher invited students to explain and to elaborate, whether their explanations were initially correct or not. By asking questions, she created a classroom context in which all students were expected to fully explain their thinking. These questions gave students guidance about how to discuss in pairs to develop accurate explanations for mathematically-correct solutions.

Some of these interventions were brief and did not directly link to immediate or long term learning outcomes, but they did suggest important design features for longer term, classroom based programs. From this research, it is clear that questioning has the potential to solicit elaborations and justifications and counter-arguments. In the case of academic discourse, questions elicit evidence to buttress an argument (Chin & Osborne, 2010). However, effective questioning is but one feature. Researchers acknowledge that in some ways, their contexts were ideal: students were cooperative and had fairly high motivation (Hogan et al., 1999). The groups that were most effective at constructing explanations may have had significant prior knowledge; children are more likely to substantially participate in class if they have higher levels of initial achievement (Kelly, 2008). There may be differential effects on children because of children's initial competency beliefs and gender. Girls, for example, show an increased need to have high competency beliefs to achieve strong content learning gains. In contrast, boys show willingness to participate in argumentation and science experiences regardless of their competency beliefs (Pino-Pasternak et al., 2010). Another factor may be that some students may have experience in discourse norms that play a part in their capacity to engage in academic discourse. In addition, having practice at home with academic discourse patterns serves students well in the school context (Heller, 2014). Students with prior experience with learning talk are comfortable and productive with it, whereas students who are new to it become aware of their lack of competence and find that their contributions are ignored or discounted (Michaels et al., 2008).

To establish more equitable participation in classroom discourse, researchers have proposed school-based programs to introduce students to discourse norms and to reconfigure roles and structures. A series of studies has evolved into the "Accountable Talk" program (Michaels et al., 2002). Accountable Talk is a dialogic pedagogy structured around specific talk moves that teachers can use to facilitate academically productive discussions. The premise of this program is that children do not participate in this activity until they learn discourse norms for scientific talk and understand the purpose of such talk. After they are taught, they develop greater proficiency. The Talk Science Primer set out these key elements for teachers to enable this kind of talk: (a) a belief that students can do it, (b) well established ground rules, (c) clear academic purposes, (d) deep understanding of the academic content, (e) a framing question and follow up questions, (f) an appropriate talk format, and (g) a set of strategic talk moves (Michaels & O'Connor, 2012). The successful implementation of this program is intended to produce "academically productive talk." Michaels and O'Connor (2015) identified four different categories of talk moves that promote student thinking: (a) clarify and share own thoughts, (b) orient to the thinking of others, (c) deepen own understanding, and (d) engage with the reasoning of others. Interestingly, it may not be necessary for students to vocalize in a classroom full of students engaged in dialogic instruction. It may be that silent students can learn by actively listening to academically productive talk. O'Connor et al., (2017) concluded that in the context of their study, there was "no appreciable relationship between measures of what a student learns from a discussion, and measures of what that student verbally contributed to the discussion." This is not to say that silent students always learn while other students are talking. The classroom context that enables all or most students to learn from listening must be intentionally and carefully established.

Scientific Discourse in School: Better Scientific Explanations. In this section, I describe how students participate in the construction and evaluation of scientific explanations using evidence. Scientific discourse is the means of generating a scientific explanation, a causal account of natural phenomena. An explanation includes an evidence-based description of what happens. It logically relates the description of the phenomenon, or explanandum, and how and why the phenomenon happens, to scientific facts or theoretical ideas, the explanans (Osborne & Patterson, 2011). The "explanans are less certain than the explanandum and are derived from observables, laws, or theories that are generally regarded to be true," (Osborne & Patterson, 2011). The explanation organizes knowledge within a comprehensive, coherent framework (de Andrade et al., 2017). In school science, explanations are thought to build conceptual understanding and are central to science education (National Research Council, 2012). By developing their own explanations of phenomena, whether based on observations they have made or models they have developed, students demonstrate their own understanding of the implications of a scientific idea (National Research Council, 2012). Engaging in this process helps students make sense of why a natural phenomenon occurs, how it happens, and why it persists (McCain, 2015). The explanation is used both as an artifact representing student learning and as a tool for students to engage in practices of scientific knowledge building.

In some classroom contexts, students are provided explanations as products of experts. Sometimes this helps learning, for instance by offering a schema that guides student observations. When students are coached in advance to observe with an outline of what scientists expect to happen and why, they are more likely to predict the correct outcome, observe the correct result, and change their conceptions. Providing explanations to students promoted conceptual change by inducing correct predictions (Chinn & Malhotra, 2002). The resulting student explanation might be regarded as an artifact by teachers to assess student understanding. However, the tendency of science educators to focus on the memorization of discrete concepts, facts, and laws, science in “final form” creates problems that can be moderated by emphasizing the process of generating scientific explanations (Duschl, 1990).

To counteract the tendency to concentrate on a canonical explanation as a final product, science educators should direct students’ efforts to making “better scientific explanations” out of their initial understandings (Papadouris et al., 2018). Better explanations can be made by improving the facts that make up the explanation, the “explanans” (Osborne & Patterson, 2011), which can include elaborated description, definitions or observations (Braaten & Windschitl, 2011). For students to understand how to improve their explanations, rather than assessing the correctness of the explanation based on how it matches a canonical one, educators should teach students to evaluate its coherence and comprehensiveness.

Students must have a process for evaluating the strength of the explanation (de Andrade, Freire, & Baptista, 2017; Papadouris, et al., 2018). One framework proposes evaluating based on four dimensions: relevance, conceptual framework, causality, and the appropriate level of representation (de Andrade, et al., 2017). Another framework bases the strength of the explanation on three factors: empirical validity, interpretive power, and generalizability. Observations that are sufficiently detailed and accurate determine the empirical validity of the explanation. Interpretive power is determined by how well the explanation can answer how and why the phenomenon occurs the way it does. Generalizability refers to how applicable it is to other situations.

By focusing students on evaluating the explanation and considering how these factors or dimensions might be improved or deepened, students might develop an understanding of how knowledge is constructed and accepted by the scientific community (Papadouris, et al., 2018). Papadouris, et al. (2018) propose a set of epistemological orientations that students should learn:

- that a given phenomenon might be accounted for by more than one explanation
- to prioritize a commitment to empirical data
- the implications of the predictive success/failure of a given explanation
- to attend to disconfirming evidence as a means of evaluating the empirical adequacy of a given explanation
- to seek underlying interpretive mechanisms for how a phenomenon of interest unfolds the way it does, offering descriptive as opposed to explanatory accounts for a phenomenon

- to expand the scope of any given explanation by seeking regularities across different phenomena

Research on the importance of understanding evidence supports these epistemological orientations. The use of empirical evidence is an essential component of science education (Driver et al., 2000; Ford, 2008; McNeill & Berland, 2017). Studies have found that in spite of direct instruction, middle school students fail to use relevant data, use inappropriate data or observations or use beliefs instead of data (Chinn & Malhotra, 2002; McNeill & Krajcik, 2007; Hug & McNeill, 2008; Hogan & Maglienti, 2001). Older students, those in high school, are more likely to use data, demonstrating their understanding that a valid explanation requires using data as evidence. However, they still fail to articulate how their claims account for the data or explicitly connect specific inscriptions to their claims, indicating their perception that data is factual and self-evident (Sandoval & Millwood, 2005). Students may construct stronger explanations if they understand why providing data rather than opinions and offering an interpretation of the evidence results in a stronger, more convincing explanation (McNeill & Krajcik, 2008). It is necessary to not only provide instruction in the use of evidence, but to offer students reasons to use it to improve an explanation.

Instruction in the Use of Evidence in Scientific Explanations. Instruction in the use of evidence is a vital part of explanation-building therefore it is important to define it for K-12 learning environments. McNeill and Berland (2017) propose that educators focus on the use of information that is phenomena-based, transformable, and used dialogically. Information is used dialogically when students work together through social interactions to make sense of it. Students engage in discourse in which they construct and critique different ideas to collaboratively build knowledge. Information is phenomena-based when it consists of empirical data (e.g., observations or measurements) about phenomena in the natural world. Data that is transformable requires students to critically consider and interpret the observations and measurements. The data must enable student sense-making by requiring that students select what data to use, manipulate it to find patterns, and evaluate the fit between those patterns and their claim. This focus may result in learning environments that more consistently enable students to meaningfully participate in the science practices. These criteria for use of evidence also provided a framework to critique the ways that instruction has failed to enable students to appreciate the importance of evidence in knowledge-building.

Some ways that teachers have tried to bring attention to the use of evidence is by introducing it as a way of solving a mystery (Villanueva & Hand, 2011). In this context, students develop an understanding of how to use observations to support a claim, what it means to say that an observation is irrelevant, and what counter-evidence is. The trouble with this is that it limits the epistemological orientations of students. The conclusions from a mystery story are not the same as a scientific explanation and sometimes leaves students with the impression that "intuition" is as valid as detailed observations. This scenario is not phenomena-based, does not include empirical data, and it is not transformable. The discussion around a mystery might lead to students presenting an observation as an answer itself, without interpretation or justification.

The instructional problem and possible solutions were tested by Hug and McNeill (2008) in their study of first-hand or second-hand data use by students. Students worked with qualitative observations or quantitative measurements that were explicitly linked to phenomena from the natural world. First-hand data experiences are those in which students collect their own observations or measurements from a phenomenon directly in front of them. Second-hand experiences are those in which students are either provided with data collected by other individuals or use a simulation that allows them to change variables and collect data. Second-hand data experiences can enable students to explore phenomena that they cannot directly experience in K-12 classrooms. Hug and McNeill (2008) found that students make claims or conclusions with adequate justification in both first-hand and second-hand data experiences when allowed sufficient time to organize the data. Conversations about data organization occur at a higher frequency in the second-hand data experiences, but first-hand experiences produce greater accuracy in claims. Students can use data evidence, identify patterns and draw conclusions, but with difficulty. These difficulties might be alleviated by reducing the complexity or amount of data with which students work. However, because the transformation of data is an essential part of explanation-building, it might be more effective to provide instruction in the organization of the data. This instruction might also aid students in discerning patterns in complex data sets.

One way that data becomes transformed is through the use of inscriptions, graphs, diagrams, data tables, symbols, maps, and models. Inscriptions are types of transformations that convey information, organize data, demonstrate patterns and relationships, and communicate scientific knowledge. A study of seventh grade students using first-hand data shows that students can design and interpret scientific inscriptions. The inscriptional activities were scaffolded by teachers and sequenced, iterated, and embedded in scientific inquiry (Wu & Krajcik, 2006). Through the inscriptions, students externalized their conceptual understandings, reviewed the inquiry process, shared ideas, and made sense of data. These students were able to produce a more coherent narrative and construct a consistent theory by coordinating the succession of instances that they observed. As students became more competent in interpreting and reasoning about inscriptions, they expressed more opinions or comments on the design of interpretations or on the conclusions drawn. They also developed more coherent arguments in their writing about data and inscriptions. The study concluded that engaging students in inscriptional activities, particularly the discussion of inscriptions, could be beneficial to constructing understandings about concepts and inquiry.

Practicing Scientific Discourse in School. Scientific explanations that are empirical, debatable, predictive, interpretive, and generalizable require discourse around data that is phenomena-based, transformable, and used dialogically. Promoting this discourse must accommodate the cognitive development of typical middle schoolers and recognize that getting students to engage in talk about evidence is a challenge. Simply including a request to talk, to explain or to justify as part of a learning task is insufficient. Without other conditions in place, the discourse devolves into procedural or irrelevant talk, rather than high-level cognitive elaboration. The solution may be to prompt students with more science-specific requests over a longer significant part of a school year. This kind of intensive approach may facilitate talk by more students and consequentially reach high-cognitive levels.

One example of the difficulty in promoting discourse was shown in a study of how cognitive tasks were enacted in middle-school math classrooms. High-level activity occurred in classrooms where clear and consistent messages were sent to students that explanations and justifications were as much a part of classroom mathematical activity as were correct answers (Stein, Grover, & Henningsen, 1996). Students were found to produce work at high cognitive levels, but not universally or thoroughly: in 23% of the cases in which the task set up required students to explain or justify their thinking, no or few explanations were actually produced. Of the 144 tasks observed, 72 tasks (or 50%) were enacted in a way that the majority of students were explaining and justifying their thinking. The positive effect of a teacher-fostered climate of high expectations is clear, however it remains that knowledge-building is not easily sustained by students on their own.

This is similar to the findings of a study of reading discussions in a fourth-grade classroom. The students were pressed to use evidence to explain their thinking but were not likely to do so. Of the 44 times the teacher prompted children to use evidence, there was 26.3% probability that her request would be fulfilled by a child in the following turn. When a child receives praise for a response, the other children might pick up that response without need for more prompting. However, the results show how difficult it is for children to pick up this specific technique. Of the three scaffolding moves by the teacher, prompting and praising use of evidence was the least appropriated by students. Only four children out of 23 were observed to ask other group members for text evidence to support their claims. Two other moves, challenging and asking for clarification were more likely to generate a response by students and to be used by students. When the teacher posed a challenge, there was a likelihood of 37.5% that a child in the following turn would respond to her challenge. Following a response to the challenge, there was a 47.9% probability that another child would respond. Even so, only six children from two of the three groups appropriated asking for clarification in later discussions. Although significant, children had a weaker reciprocal impact on each other than the teacher’s scaffolding actions. (Jadallah, et al., 2011)

Despite a teacher’s best efforts, scientific discourse is hard to elicit. One problem is that sustaining good questions that help students “think, analyze, criticize, and solve unfamiliar problems” (Lin, et al., 2015) is hard for teachers, too. Teachers often use prompts encouraging participation, answering challenges, clarifying, focusing on topic, and giving reasons. However, asking open-ended questions that reveal student thinking is less common. And whereas explicitly modeling the use of questions such as “how would you support this claim?” might be a more effective scaffold (Songer et al., 2013), these types of questions are rarely observed or pursued.

When teachers and peers use effective strategies, it is possible for students to learn and practice academic discourse. This was demonstrated in a fifth-grade science classroom over an eight-month period. The teacher influenced student talk by using a form of communication labeled “double talk,” when a speaker assumes someone does not understand one version of a term and offers two versions of the same idea. In small groups, students continue to use this double talk strategy. In sequences coded as “explanations with embedded definition,” students defined the words they used in their descriptions. The authors concluded that making the language of science explicit can lead to a discursive environment where the situated nature of scientific language learning allows students to attempt to simultaneously appropriate scientific language and develop conceptual understanding. Though not claiming a causal connection, the authors note that the students in this class had the highest academic performance of all fifth-grade classrooms. The teacher’s approach to using vernacular and scientific ways of explaining phenomena has the potential to impact student learning from discussion (Brown & Spang, 2008).

Educators looking for knowledge-building hope to see more occurrences of “uptake,” students repeating a discourse strategy after observing it modeled by a teacher or peer. Anderson and colleagues (2001) called child-child influence the ‘‘snowball’’ phenomenon. They found that once a useful argument move is employed by a child, it spreads among the rest of the children and occurs with increasing frequency. What would it take for more children to pick up a useful strategy? Sustained teacher-directed effort or explicit teaching of scientific discourse as an academic language (Brown & Spang, 2008) may be required. Intensive practice both in oral and written discourse with teacher support may be necessary. The students must recognize the positive impact of their practice on their learning, acknowledge the learning and appropriate the discourse moves as an effective strategy.

One form of discourse that might have an impact on student learning is argumentation, in particular, the uptake of specific scientific argumentation talk moves. Argumentation, a process of working through disagreements, may be more effective than collaborative explanation-building. Exploring differences in understandings and disparate ideas through elaborated talk and resolving these conflicts may lead to better and more lasting learning (Nussbaum, 2008). The next section discusses the use of “dispute prompts” to help promote this form of discourse.

Dispute Prompts. Asking students to consider a competing claim, evaluate the evidence given to support that claim, and justify their reasons for disputing might be a way to improve explanations. This powerful form of discussion, sometimes known as “mediation,” entails the constructing of arguments by pointing at contradictions, bringing new data, challenging an argument (Andriessen & Schwarz, 2009). This form of discourse will give students both a reason and a means to improve their argument through the use of evidence, a key to student learning (McNeill & Krajcik, 2008). It might improve their explanations because one way that students fall short of a creating a “better explanation” is by failing to incorporate or explain disparate data. Students may incorporate data that goes against their explanation, but many times, they ignore such data (Chinn & Brewer, 1998). Student learning might be improved through discourse that demands students account for all data, including disconfirming data. As Osborne and Patterson (2011) note being able to identify why one explanation is wrong matters just as much as being able to explain why another is right” (p. 636).

This discourse process is only possible if students are presented with a complex phenomenon in which the explanans has multiple plausible paths or possible conclusions. The power of learning through competing explanations led to its inclusion in the NGSS framework: "…explanations are especially valuable for the classroom because of, rather than in spite of, the fact that there often are competing explanations offered for the same phenomenon." (National Research Council, 2012, p. 68). The NGSS, with the goal of making school science as close as possible to the work of actual scientists, recommends that educators teach students the process of deciding on the best explanation.

Teachers might help making competing explanations available for class discussion by using dispute prompts as argument moves. Teachers could use the phrase, ‘‘some people might say [counterargument]’’ to introduce an alternative point of view. They might also introduce data that seems to go against the students' preferred explanation and ask students to decide whether this data is disconfirming or might be accommodated by a revised explanation. This strategy might help students develop a basis for judging the plausibility of various explanations, a skill endorsed by Sandoval and Millwood, 2005. They found that though students gave explanations that were plausible and accounted for some evidence, they required more help in developing sound bases for judging plausibility. They advocated this technique because it helped competing explanations become available for class discussion (Sandoval & Millwood 2005).

Setting up a dispute might lead to more justifications than just asking students to provide them. One study showed that even five-year olds can produce explanations by justifying their opposition during a disagreement (Orsolini & Pontecorvo, 1992). They described a dispute phase of discussion beginning with the denial of a previous claim. This response might be an elaborated opposition providing a justification with the intention to convince the recipient of the speaker's claim. The opposition is presented as a claim that contains contrasting or corrective information. The elaborate opposition might receive either a simple rejection ("It's not true" or

"No") or a counter-opposition in which the recipient's claim is denied and some kind of reason is given. Counter-opposition turns are generally followed by more counter-opposition. Some counter-opposition turns concentrate on defending one's own previous claim by elaborating some information that might undermine the opposer's claim. In disputes, children's justifications of opposition forces the speaker to reconsider his or her own previous claim.

To produce argumentative talk, students must encounter a high-level, interesting task in which they feel able and encouraged to take a position. For middle school students, developing and using models might be the context that provides the topic to discuss. Science education researchers emphasize the use of models in explanation-building “because explanations are constructed from models and representations of reality—not out of data and warrants.” They specify that argumentation often involves comparing different explanations for natural phenomena in an evidence-based way (Bell & Shouse, n.d.). Furthermore, the NGSS Framework recognizes that “Because scientists achieve their own understanding by building theories and theory-based explanations with the aid of models and representations and by drawing on data and evidence, students should also develop some facility in constructing model- or evidence-based explanations. This is an essential step in building their own understanding of phenomena, in gaining greater appreciation of the explanatory power of the scientific theories that they are learning about in class, and in acquiring greater insight into how scientists operate” (National Research Council, 2012, p. 68). In the next section, the process of developing and using models as a context for argumentation is discussed.

Modeling as a Learning Process

Students learn through their active participation in science practices, thus the specific practice of developing and using models is prescribed by the NGSS. School science programs known as “model-based reasoning” or “model-based inquiry” have been used to help students develop and demonstrate knowledge through the building of explanatory models. Like explanations of phenomena, models can be considered a process or a product. Passmore and Svoboda (2012) propose that modeling is powerful because it is about judging ideas and making sense of them; convincing oneself or others that the ideas and ways of looking at and explaining a phenomenon are useful. These mental, written or oral persuasive acts, from developing a question to judging between competing models that might answer that question, are intellectually interesting and challenging. Inviting students into this practice is one way to help them learn both the content and process of science (Passmore & Svoboda, 2012).

The intellectual challenge of model building requires a variety of cognitive strategies. Pluta et al., (2008) list them as: (a) constructing models on the basis of evidence, (b) revising models in the light of additional evidence, (c) convincingly justifying models, (d) evaluating alternative models using multiple sources of evidence, and (e) generating explanations and predictions from alternative models. In the next section, I describe the research that describes guidelines and protocols for scaffolds to support students as they learn to build models and develop their understanding of models.

Models for Students. For experts, a scientific model explains and predicts scientific phenomena. It is a representation that focuses on key features to abstract and simplify a system (Schwarz et al., 2009). For students, models are used to support learning about a scientific concept, a visual scaffold that explains the ideas of others. Often, they are provided as a product, such as a diagram or a replica. Because they are not engaged in the process of model-building as a reflection of their own thinking, middle school students think that models are either toys, examples or demonstrations, or copies of reality and that all representations are models

(Grosslight et al., 1991). Students do not recognize the value of a model as an aid in the construction of scientific explanations. Only three percent of the mixed-ability 7th graders and 14% of the honors 11th graders mentioned that a model could help you understand and form an explanation about why something works (Grosslight, et al. 1991). These interpretations may be improved. In Pluta et al.'s (2011) work, middle school students showed willingness and ability to link the goal of explaining to the purpose of scientific models with some minimal instruction (Pluta et al., 2011).

Students are offered a variety of forms of models in middle school science, often used as a way to communicate the ideas of expert others. Unfortunately, students often get the sense that this represents is a single correct answer and are left with a narrow or shallow understanding of science. Though one purpose of models is to communicate ideas to others, students might learn more from understanding their own ideas and conveying them. A better understanding of the phenomenon and the process of scientific knowledge-building might occur if students present their own model to others. In the process of articulating their model, students may need to provide justifications or revise it in order to persuade others. In addition to using models to enhance explanations, students might also learn that models can be used to generate questions to investigate or generate data that can be used to make predictions.

Learning Goals of Modeling. Science education can help students learn that models can be mental, written or oral, visual or physical and can be used to communicate information about real things. Students also learn that models do not correspond exactly to the real world, they bring certain features into focus while obscuring others (NGSS). The NGSS includes explanatory, predictive models because they are a prevalent form of model in contemporary science; hence learning to develop, revise, select, and use explanatory models is an authentic practice of scientists (Pluta et al., 2011).

The use of models includes but is not limited to, illustrating, explaining, and predicting phenomena. Students learn that models are varied in form and purpose, have limitations, are built on evidence, and can be revised (Lohse et al., 1994). Students recognize that all models contain approximations and assumptions that limit the range of validity and predictive power; some models may ignore some information in order to enhance other information (Grosslight et al., 1991).

The NGSS aims to have students see models as a way to illustrate, explain or predict the mechanism, causes or functions of a phenomenon. Specifically, the goal of Practice 2, developing and using models in grades 6-8, is to have students:

· Evaluate limitations of a model for a proposed object or tool.

· Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed.

· Use and/or develop a model of simple systems with uncertain and less predictable factors. · Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.

· Develop and/or use a model to predict and/or describe phenomena.

· Develop a model to describe unobservable mechanisms.

· Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.

In a NGSS-aligned class, students expand their definition of a model as a representation of a system. By focusing on model-building as much as the use of a model-product the assumptions that underlie the representation are made explicit (Lohse, Biolsi, Walker & Rueter, 1994). Students understand that model construction is influenced by certain intentions and purposes and that there can be multiple models for a given reality. These purposes include teaching, highlighting, explaining, and communicating rather than simply playing or showing. They learn that models, in the form of maps, charts, pictures, diagrams, replicas, mathematical representations, analogies, and/or computer simulations might be used to develop questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. The goal is to engage students in the process of model building as much as the use of a model as a product because model-building activates deeper student thinking.

Thinking About Modeling. The focus on the process of model-building rather than on the product originates from the constructivist philosophy that knowledge must be built within the individual mind rather than transmitted from one person to another. Model building is a conceptual task that asks students to think about how parts of the model are related to parts of the real thing, how it visibly represents a process that is too complex or an object that too small or too big to see in real life, or how the model can represent a "what if." Model building also gives students a chance to engage in complex thinking, making sense of different ideas and evaluating competing ideas. Students build a model to try to understand a phenomenon and in the process, clarify their thinking and develop group consensus (Schwarz, et al., 2009). The discourse around the model involves convincing oneself or others that the ideas and ways of looking at and explaining a phenomenon are useful, has the potential to lead to conceptual change (Passmore & Svoboda, 2012). This potential of modeling to advance student thinking is why the NGSS has named it as an essential scientific practice. Model-based reasoning is one promising avenue to promote authentic reasoning in classrooms (Duschl et al., 2007).

Thinking about scientific modeling includes the metaknowledge that guides and motivates the practice (e.g., understanding the nature and purpose of models). Middle school students can improve understanding the nature and purpose of models (Schwarz et al., 2009). In this study, fifth and sixth graders were shown to productively engage in constructing and revising increasingly accurate models that included powerful explanatory mechanisms and applied these models to make predictions for related phenomena. Students moved from illustrative to explanatory models. They also developed increasingly sophisticated views of the explanatory nature of models, shifting from models as correct or incorrect to models as encompassing explanations for multiple aspects of a target phenomenon. They also developed more nuanced reasons to revise models (Schwarz et al., 2009).

This suggests that students can learn why and how explanatory model-building is an important aspect of scientific thinking. They may be supported in their learning with help from an emphasis on the evaluation of models. For middle school students, this might mean gathering and applying evidence and comparing how different models accommodate observations of qualitative or quantitative data. By engaging in this process, students might come to understand "their own knowledge or ideas as potentially disconfirmable" and as contingent upon evidence" (Passmore & Svoboda, 2012), a significant marker of learning to think scientifically.

Evaluating Models. In the process of building an explanatory model, students should be encouraged to think about how the model fits their observations of the phenomenon. By gauging how well evidence potentially supports their own model and other models proposed by others (McNeill et al., 2006), students engage in a cognitive exercise of critical evaluation. Critical evaluation introduces to students the idea of falsification, where evidence may rule out one idea in favor of another.

In school science, students learn to evaluate and refine models as part of NGSS practice #2. This might involve comparing an original model to a potential new model and recognizing how it attempts to understand a phenomenon differently. They might test each model by comparing predictions against real data. This leads to an evaluation of fitness: how well each model accommodates the information. When a model cannot account for new observations and data, it might be called model misfit. Students then make adjustments to incorporate new evidence or to encompass a wider array of situations (Lehrer & Schauble, 2010). Revising models builds their explanatory and predictive power and scope. In this process, students learn that models are based upon evidence and more evidence improves models.

A significant advantage of model building is that it involves both the cognitive and the social components of inquiry (Grosslight et al., 1991). Critical evaluation is a cognitive component and collaborative argumentation is a social component. They are even more effective when practiced together. Chin and Osborne (2010) suggest that critical evaluation is stimulated by argumentative discourse activities, where students challenge each other’s thinking through questions. Students who engage in critical evaluation understand that scientific knowledge emerges from collaborative argumentation, which is a constructive and social process where individuals compare, critique, and revise ideas (Nussbaum, 2008). Using models as an argumentative focus can stimulate questions about the relationship between the evidence and various models and the strengths and weaknesses in the connection between them. Evaluating rival models is a form of argument (Grosslight, 1993; Lehrer & Schauble, (2006). Judging between competing models that might answer a question is an argumentative action.

Improving Models Through Argument. Models as a focus for argumentation are effective because they present a visible artifact of student thinking and a topic for conversation (Lehrer & Schauble, 2010; Passmore & Svoboda, 2012). A model can be thought of as a form of claim, an assertion that responds to the observations, analyses, and/or phenomena in question. In the claim-evidence-reasoning framework, students use their observations, data or information to support their model, however they must also make their reasoning explicit in order for it to count as evidence. Evidence is a judgment consisting of data and reasoning to show how or why the claim should be supported (Chen et al., 2013). The reasoning is the justification that links the evidence in support of the claim, or the use of scientific ideas or definitions to explain or interpret the evidence. To make the reasoning explicit, students might be pushed to explain how the evidence supports their particular model or contradicts another model.

In modeling, student dialog centers on how the evidence "fits" different models of the same phenomenon. Participants learn to expect that problems can be addressed with a variety of models and representational forms and that they must present justifications for their model against alternatives. In the process, students use the model to identify evidence for knowledge claims, develop models using social negotiation process and change/refine them as observations and new information are reinterpreted, and use an array of models to represent ideas (Lehrer & Schauble, 2006).

Collaborative argumentation around model building might help with several challenges that arise in school science classrooms. First, students need an authentic reason to do it, second, they need an audience for their thinking, and finally, they need a reason to revise their model (Schwarz, et al., 2009). Students who lack prior experience are unlikely to be productive because they do not try to resolve conflict between different ideas and they often leave out justifications and reasons in their final products, whether it is an explanatory model or an oral or written explanation. There is a need for scaffolds to help students turn data into evidence by expressing how the information supports a causal relationship (Koslowski et al., 2008), to communicate and critically evaluate the ideas underlying their models (Kenyon et al., 2008) and foster deep cognitive processing.

Evaluating Models With the Help of Scaffolds. To address the challenges of model-building and to realize its potential to enhance student thinking, the scaffolding design framework proposed by Quintana et al. (2004) offers suggestions. These guidelines include using visual representations to support sensemaking, highlighting epistemic characteristics of the product and providing reminders, guidance and support for planning and monitoring articulation and reflection during argumentation.

Students need scaffolds specifically designed to promote articulation and reflection on the relationship between evidence and models. Some examples of scaffolds include the Progress Portfolio (Kyza & Edelson, 2005) and Knowledge Integration Environment (KIE) SenseMaker (Bell, 1997). These tools make explicit the underlying assumptions of a model and encourage critique of evidence through argumentative discourse. These scaffolds offer different supports to link claims and evidence. The Progress Portfolio uses question prompts and KIE SenseMaker is a visual representation of the argument. Using SenseMaker, the students group evidence items into categories and create scientific arguments based on their understanding of the topic. As they do this, the students are also prompted to rate the evidence and claims on different dimensions, such as usefulness (Bell, 1997).

Another scaffold that has been effective in learning environments using models is the Model Evidence Link (MEL) matrix. The MEL aims to make the scientific practice of critical evaluation explicit through model-based reasoning and argumentation (Chinn & Buckland, 2012). The MEL matrix is a graphical organizer designed to facilitate systematic model and evidence evaluation. It helps students engaging in inquiry by highlighting differences in interpretations and promoting discussion about different ideas. It offers structure to dissect tasks, focus effort, and monitor progress. The MEL matrix provides a graphical organizer for student thinking about the quality of evidence and the evidence's relation to the models (Rinehart, Duncan & Chinn, 2014). It has been used to aid students who have been assigning the task of choosing the explanatory model that best fits the evidence (Chinn et al., 2008). Student use of the MEL matrix is mediated by social processes including dialog with peers and parents. The MEL matrix is used to initiate argumentative discussions and to serve as a record of student thinking. Teachers can use the MEL to problematize the evidence by asking students to make a decision about whether the evidence supports or opposes the model.

To summarize, the research reinforces three principles of science learning that support the proposed learning environment for this study. First, planning and attention to a variety of factors is necessary to create environments in which learning talk is nurtured and becomes the norm. There are limits to the approaches that improve student participation in scientific discourse. Programs that focus on scaffolding general discussion skills may help students successfully and spontaneously generate academically productive talk. In some of the programs, students are enculturated into the dialogic practice for several months or years before most students are seen to participate and benefit (Crowell & Kuhn, 2014; O'Connor et al., 2017). Programs that work with children for as many as three years can build argumentation skills in many children and improve their reasoning. Other programs that are shorter in duration can succeed in getting some children to use specific argumentative moves (such as citing evidence from texts or justifying predictions. However, these are not effective at getting all or even most children participating and are not linked to learning outcomes. The presence of a skilled teacher leading small group discussions is beneficial, but small-group peer discussions can veer off-topic and leave some students disengaged. In short, what we know about setting up learning environments that promote productive learning talk, or academic discourse, is not enough to ensure that all students have an opportunity to participate and to learn in such an environment. Instead, studies have shown that for academic discourse to become a characteristic of a school community, "it must be *socialized*, learned by living daily for many months and years in an environment that expects such behavior, supports it, and rewards it in overt and subtle ways" (Resnick et al., 2010, p. 172). Therefore, approaches that leverage other resources, including parents, should be explored.

Second, when a learning environment is successful at getting students to differentiate between data and evidence and to use evidence to justify their explanations, it results in greater conceptual understanding. Finally, model building as an authentic scientific practice has the potential to provide a structure and a purpose for collaborative argumentation. Because this practice is challenging, scaffolds for coordinating evidence and evaluating models are proposed.

Family Engagement

Parents have reported a desire for resources that would help them engage in science learning activities and encourage their child's interest (Silander, et al., 2018). Many parents of young children already have science-related conversations with their children, including informal discussions about the natural world (Silander, et al., 2018). Such talk has been shown to improve children's understanding in informal learning environments such as museums and zoos (Allen, 2002; Callanan & Oakes, 1992; Crowley et al., 2001; Eberbach & Crowley, 2017; Gleason &

Schauble, 1999; Haden, 2010; Szechter & Carey, 2009). Studies of families in free choice learning settings have uncovered talk characteristics that impact what children learn from their experiences (Eberbach & Crowley, 2017). Parents spontaneously use a variety of strategies: describing evidence, giving direction, providing explanation, making connections, and eliciting predictions (Szechter & Carey, 2009). The use of these strategies familiarizes children with talk that can lead to learning in formal academic settings.

In many families, questioning and explanations are used prolifically to expand language and understanding. However, socioeconomic privilege, parental education, home language, and gender affect family discourse (Crowley et al., 2001, Szechter & Carey, 2009). These factors influence family discourse, which has an influence on children's school experiences. Michaels et al. (2008) recognized students with prior experience with learning talk are comfortable and productive with it, whereas students who are new to it became aware of their lack of competence and found that their contributions were ignored or discounted (Michaels et al., 2008). These differences carried over into school and affected students' participation in school (Engin, 2016; Morek, 2015; Heller, 2014).

Educational interventions have shown that parents can be trained to offer helpful talk. This training can make a difference in the learning outcomes of the students in informal settings like science centers (Boland et al., 2003; Jant et al., 2014; Szechter & Carey, 2009). Other interventions with mothers of young children confirm that parents are trainable and that the training affects the child's memory. For example, children of trained mothers recalled more embellished details of a camping experience than did children of untrained mothers, (Boland et al., 2003). Home interventions to increase learning talk have been shown to affect school behavior (Chng et al., 2014; Engin, 2016; Mattanah et al., 2005; Neitzel & Stright, 2003).

The specific type of talk that to encourage parents to use may be important. Some studies prompt parents to use “wh-” questions in museum exhibits (Benjamin et al., 2010; Jant et al., 2014). These types of questions are associated with greater recall by children, as well as differences in use of materials and learning assessments (Benjamin et al., 2010). Tscholl and Lindgren (2016) gave conversational scaffolds to adults as their children experienced an augmented reality exhibit. In addition to task-specific visuals, the adults were cued to use questions such as “what is going on here.” These questions prompted children to plan, think ahead, and reflect. These actions can help children build understanding and support science learning (Tscholl & Lindgren, 2016).

Involving parents can prepare students to engage in productive scientific discussions. The challenge is to provide a structure in which parents can engage with their students productively using their prior experiences. As an accessible and responsive audience, parents can scaffold their children’s argumentative competence by practicing this specific type of discourse skill (Schwarz et al., 2009).

CHAPTER 3: METHODS

The purpose of this design-based intervention study was to support parent-child interactions in the context of scientific inquiry by offering instruction, training, and scaffolds. In this chapter, I explain the methods that guided the design and execution of the intervention and collection of data. I describe how I developed the features of the intervention, the instruction, training, and scaffolds. I also describe the instructional procedure, materials, assessments and consent process. Lastly, I describe the analyses used. The goal was to understand parent and child talk moves that are associated with productive discourse and may contribute to student learning.

Participants

The study was conducted in a suburban New Jersey middle school with approximately 680 students in grades six through eight. The researcher had taught middle-school science in this school for ten years and was the sole teacher in the four class sections under study. Each section was a stand-alone class of 23 to 26 students, a subset of the sixth-grade student population of about 200 students. There were 95 students in these four sections. The students were assigned randomly to classes without input from the teacher/researcher. Students who had an Individualized Educational Plan (IEP) were not assigned to the sections in this study. Students who had learning or attention issues that are addressed through a 504 plan were included in the classes under study.

The parents and students who participated are part of a school system that serves a wealthy, well-educated community. While demographic information on the specific participants was not collected, demographic information about the community puts the results in context. Families in this town have a median income of $164,657 (mean $223,934). The majority of families (70%) are headed by a person with a Bachelor's degree or higher, and 96% of the adult population are high school graduates. (U.S. Census Bureau, 2011-2015 American Community Survey 5-Year Estimates).

The state Department of Education reports that the largest racial/ethnic group in the school's student population is white students (62.9%). The second largest group is Asian students (21.0%). Hispanic students are 9.9% of the school population, Black students are 1.4% and Pacific Islanders are .2%. Multiracial students are 4.6%. Most students speak English at home (85.5%). Students also speak Chinese (3.2%), Portuguese (2.5%), Spanish (2.2%), and other languages (6.5%). According to state criteria, less than 1% of students are identified as English Language Learners (.6%) or economically disadvantaged (.3%) Almost 80% of students met or exceeded expectations on the state assessments for English Language Arts or Math (New Jersey School Performance Summary Report. 2018-2019).A baseline writing task was conducted for all students as a usual practice in the beginning of the year, confirming that the achievement profile of each class was similar. No class had a larger proportion of high-achieving or low-achieving students than another. Each class had an approximately equal number of students who consented to participate in the study. Students were not required to participate in the study and were not penalized for opting out.

Consent

All students in the classes were invited to participate in the study. An announcement was sent home to their parents explaining that the students' classwork and homework would be collected and analyzed, anonymously. This letter stated that students were not required to participate, and that if they chose not to participate, there would be no impact on their participation in the science class or their grades. All students were asked to assent to their work being used in the study and to assent to audio and video recording (see Appendix A for assent and consent documents).

Parents/guardians were also asked for consent. Parents were sent an announcement video about the study and a link to the consent form. This form advised parents that they could participate in a recording at home and this recording and video recordings of their children's participation in school would be used for research purposes. When parents submitted the form, a copy of their form was sent to their email for their reference.

Though video-recording is standard practice in this school, all students in all classes were asked to assent to use of the recordings in the study. Students who did not assent or who had parents who did not consent were assigned to small groups where the discussion was not recorded. These children participated in the instruction and all assignments but their data was not included in the study.

Students initiated the at-home recording on their own and some chose to cover the camera so their voices could be heard but their faces were not visible. These recordings were uploaded to Google Drive and stored on the school server**.** The digital recording application, Flipgrid, is promoted as an educational tool by the school's technology coordinators because it is integrated with Google and is simple to use. Because the students are under age thirteen, it must comply with the Children's Online Privacy Protection Act, a standard procedure that this school observes when permitting students to access any app or website. Flipgrid's privacy policy is here: https://legal.flipgrid.com/privacy.html

Assignment

The students were assigned randomly to class sections without input from the teacher/researcher. Students in all classes were assigned to groups of three or four students based on compatibility and prior academic achievement based on an initial writing task. One group from each class was selected for video recording. The students in these groups represented a range of academic achievement and class engagement including some students who were typically active in class discussions and homework assignments and some who were not.

Context

The sixth-grade science curriculum is based on the Science and Technology Concepts for Middle School program (National Science Resources Center, 2006). The study began in the spring semester after students completed an inquiry-based unit during which they modeled the Sun-Earth-Moon system, recognized and made distinctions between different planets based on their surface features, and conducted investigations to find relationships between variables. The unit on Earth's tectonic processes was adapted from a variety of sources, including the PRACCIS group (Promoting Reasoning And Conceptual Change In Science [PRACCIS], 2020), Model-Based Inquiry (Model-Based Inquiry, 2020), Argument-Driven Inquiry (Argument-Driven Inquiry, 2020), Ambitious Science Teaching (Ambitious Science Teaching, 2020) and the STC Catastrophic Events curriculum (National Science Resources Center, 2006).

The objective was for students to "understand that plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geological history. Plate movements are responsible for most continental and ocean floor features and for the distribution of most rocks and minerals within Earth's crust. Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart" (NGSS Lead States, 2006).

Science instruction at this school is enriched by the students' access to their school-assigned Chromebooks. These internet-based devices were distributed to the students at the beginning of their fifth-grade year. The students would take their devices home every night, partly because homework assignments in science and other subjects are often posted on Google Classroom. In science, students used web-based simulations and interactives as well as videos and other supplemental resources to help with their understanding. They also routinely created and shared Google docs. In addition to the suite of tools known as Google Apps for Education, the school makes a variety of other resources available to the students, including reference materials, presentation tools, and educational game sites. For example, in November, students used Flipgrid to record their orbit models and presented them as videos rather than as live oral presentations. By January, students were familiar with a variety of ways the Chromebook can support learning.

Regular collaboration in small-group work was another important aspect of science class. Students were assigned to small groups for about ten weeks and then reassigned to new groups. Depending on the number of students in the class and the activity, there might have been four to six groups of students per class, with three to six students per group. Students were encouraged to use respectful talk and active listening in their small groups. Discussion prompts were posted on the walls of the classroom, as well as other classrooms in the school, to facilitate talk and listening to each other's ideas. Classes met every day for about 52 minutes.

Research Design

The study was a design-based research study. The in-class instruction for all four classes was the same for the duration of the study, which encompassed an 11-day unit of study in spring 2019. The intervention consisted of training, instruction, and guidance provided to parents and students. Two class sections consisting of approximately 50 students were assigned to participate in the treatment intervention first. The results from the participation of these first two sections were used to inform the revisions for the last two sections, with a one-week period in between to revise features of the instruction, training, and scaffolds. After the first two sections completed the unit, the second two class sections participated in the revised intervention. The two afternoon classes were randomly assigned to the first round and the two morning classes were assigned to the second round.

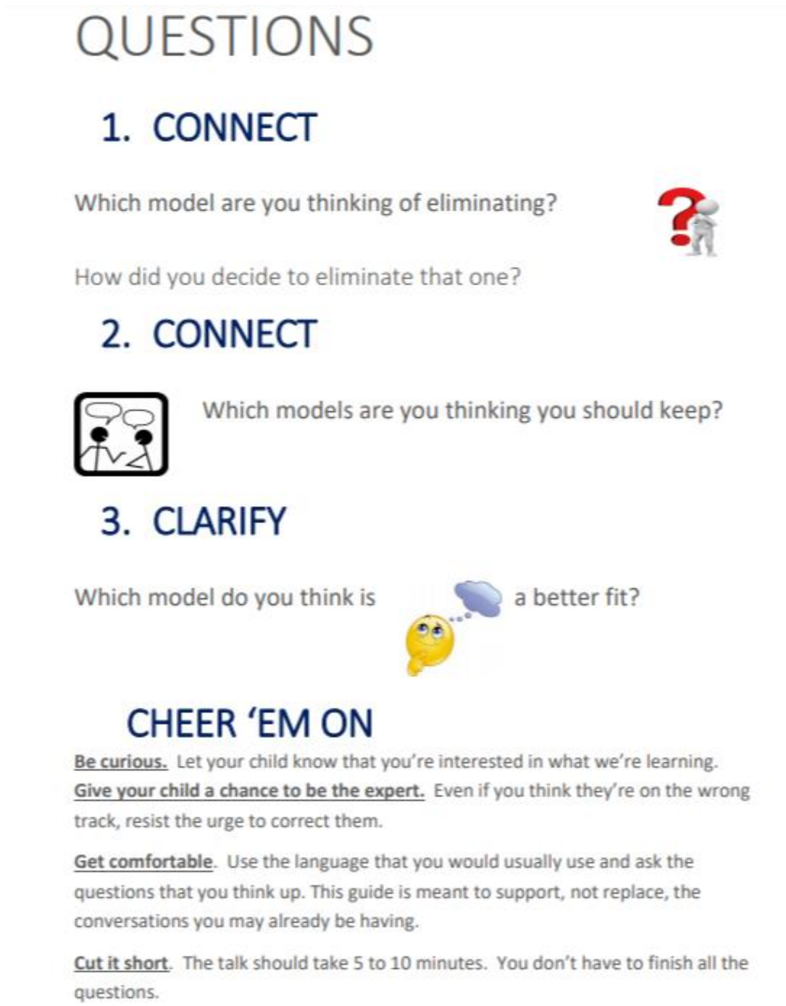
Communication With Parents

The regular method of sharing information with parents was to update the district-hosted teacher webpage, to post assignments and grade in an online grade portal and to send emails to individual parents. For this intervention, I created a group email list for the guardian contacts of the students in each section using the “bcc” line so the recipients could not be identified by others. The first time I used the group email was to send a video with pictures of the students in class, letting parents know about the topic of our current lessons and inviting them to talk with their children about the topic. The video had text titles and captions and the audio was my voice. The video was less than 3 minutes long and was in mp4 format to make it easy to access on a variety of devices. I sent it in email with a brief note describing it and asking parents for feedback and especially to let me know if they could not open it. The responses indicated that it was accessible, though some said it took a long time to load.

During the intervention, parents received through email an announcement flyer, an invitation video, a training video, instructions for the task, and a reference sheet with suggested prompts. They also were given a paper reference sheet if it was delivered by their student. The theme of the guidance was that science is a way of making sense of natural phenomena, that understanding science as an undertaking is an advantage in the classroom and in life, and that school science is a problem-solving process more than a rote memorization exercise. The guidance discouraged parents from giving explanations or other answers. This message was conveyed both directly, in the videos, and indirectly in the suggested prompts on the reference sheet.

The announcement flyer and the invitation video (Appendix B) explained the goals of the project and how the project is intended to help students. It encouraged parents by describing the expected benefits of talking with students about what they are learning. The training video (Appendix C) described how parents could use the talk prompts to encourage students to justify their scientific explanations and included specific instructions for the task. The instructions and the prompts were changed from Round 1 to Round 2. In the first round, instructions for the task were: “Help your child explain why they will rule out one of the models as a possible explanation for the Axial volcano.” The reference sheet (see Figure 1), designed as a flowchart, was distributed on paper to students and sent by email to the parents.

The suggested prompts were developed based on “best practices” from two sources: observations of families in museums and other free choice learning environments and the conceptions of science embedded in the Next Generation Science Standards. Children’s engagement in sense-making at exhibits at museums is positively correlated with parents’ requests for explanation and negatively correlated with parents giving explanations (Callanan, et al., 2017). Therefore, the suggested prompts were open-ended questions. The parent prompts were written to draw out student evaluation of models based on the evidence. Figure 3 is the reference sheet for Round 1 and shows the suggested prompts. Student instructions are explained in the next section.



QUESTIONS

1. CONNECT

Which model are you thinking of eliminating?

How did you decide to eliminate that one?

2. CONNECT

Which models are you thinking you should keep?

3. CLARIFY

Which model do you think is a better fit?

CHEER 'EM ON

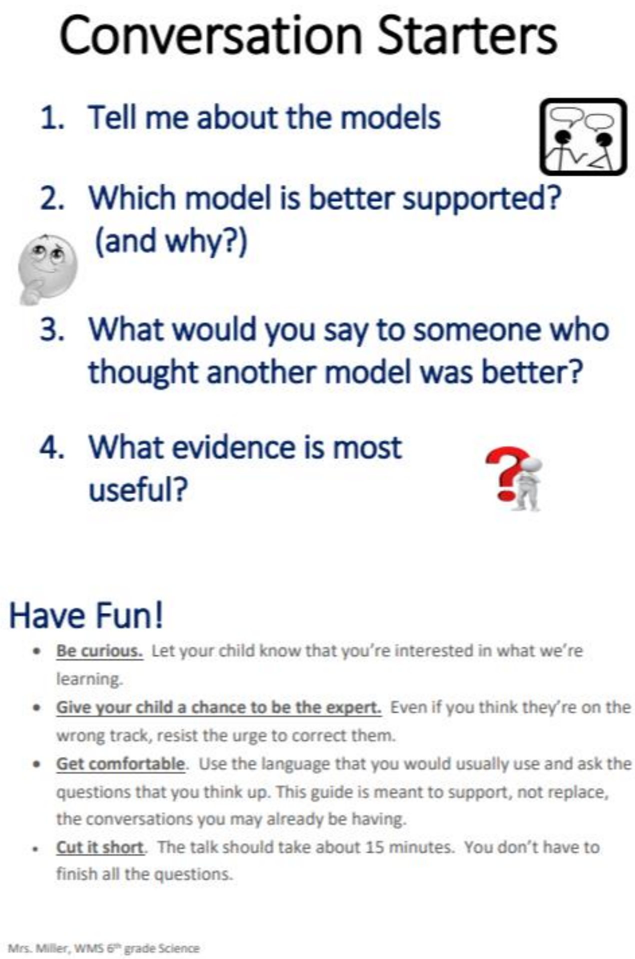
Be curious. Let your child know that you're interested in what we're learning.
Give your child a chance to be the expert. Even if you think they're on the wrong track, resist the urge to correct them.

Get comfortable. Use the language that you would usually use and ask the questions that you think up. This guide is meant to support, not replace, the conversations you may already be having.

Cut it short. The talk should take 5 to 10 minutes. You don't have to finish all the questions.

Figure 3. Parent Reference Sheet Round 1

In the second round, there were significant changes to the instruction and the prompts. The instructions to the parents were to help students compare the models and decide which one is best supported. The prompts were changed in form and in order. These changes were a result of a preliminary review of Round 1 responses, which showed that longer, more elaborate responses from students were evoked by parents making up their own questions. The first prompt became "tell me about the models" and the title of the page changed from "Questions" to "Conversation Starters." Figure 4 shows an image of the Round 2 parent reference sheet. Table 1 is a comparison of the prompts in each round.



Conversation Starters

1. Tell me about the models
2. Which model is better supported? (and why?)
3. What would you say to someone who thought another model was better?
4. What evidence is most useful?

Have Fun!

- **Be curious.** Let your child know that you're interested in what we're learning.
- **Give your child a chance to be the expert.** Even if you think they're on the wrong track, resist the urge to correct them.
- **Get comfortable**. Use the language that you would usually use and ask the questions that you think up. This guide is meant to support, not replace, the conversations you may already be having.
- **Cut it short**. The talk should take about 15 minutes. You don't have to finish all the questions.

Mrs. Miller, WMS 6th grade Science

Figure 4. Parent Reference Sheet Round 2

Table 1

Suggested Questions in Round 1 and Round 2

Round 1 suggested questions	Round 2 suggested questions
Which model are you thinking of eliminating?	Tell me about the models
How did you decide to eliminate that one?	Which model is better (or best) supported? (And why?)
Why didn't you eliminate this other model?	How would you revise it to make it even better?
Which models are you thinking you should keep?	What would you say to someone who thought another model was better?
Which model do you think is a better fit?	What evidence is most useful?
Why would you say this evidence supports both models?	

Instructional Procedure

The unit consisted of a variety of student activities and pedagogical strategies including collaborative work, direct instruction, demonstrations, and gathering information designed to help students develop an explanatory model of volcano formation. The guiding question was "What can volcanoes tell us about how plates are moving?" The student objective was to explain what might be contributing to or causing the Axial volcano to be located where it is. Students had opportunities to gather data and test and refine their models based on their evidence. The instruction was supported by an array of materials, scaffolds and tools, used both in class and at home. A complete instructional plan can be found in Appendix E.

Learning Activities. The unit lesson plan described how students were supported in their learning, what guidance they received through the process, and how they demonstrated their learning. The primary learning objective was that students would be able to construct an explanation based on geologic evidence for the movement of tectonic plates and the shaping of continents through constructive and destructive geological processes. They would be able to identify and explain patterns in the locations of mountain ranges, deep ocean trenches, ocean floor structures, earthquakes, and volcanoes. Two critical learning activities were analyzing and interpreting data and the whole-class and small group discussions. Discussion occurred throughout the unit and helped guide students as they gathered and evaluated evidence and generated and tested models. An overview of the timeline and activities is presented in Table 2.

Table 2

Learning Activities and Timeline

Day 1 Objective: formulate guiding question "What can volcanoes tell us about how plates are moving?"

- Discussed prior understandings of earthquakes and plate boundaries.
- Watched video of anchoring phenomenon (erupting underwater volcano).
- Solicited questions from students such as: What are volcanoes? How do they erupt? What causes them to form? Where do volcanoes form?
- Told students "Our objective is to explain what might be contributing to or causing the Axial volcano to be located where it is."
- Drew a model of what might be happening inside Earth to cause the Axial seamount to form. Asked students to draw on the back of observation chart and add title and labels.

Day 2 Objective: Analyze data from volcanoes, topography, and age of seafloor.

- Posed question, "How are volcanoes related to other landforms and age of the sea floor?"
- Introduced evidence summary table
- Translated observations into evidence

Day 3 Objective: Develop a model that explains how Axial came to be where it is.

- Reviewed preliminary hypotheses
- Used observations to draw group model
- Critiqued models

Day 4 Objective: Analyze data of earthquake depth and volcanoes

- Mapped and define "subduction zone," using earthquake depth profile and animation
- Demonstrated motion at plate boundary using foam pads

Day 5 Objective: Contrast volcanoes on land to underwater volcanoes.

- Observed GPS vectors showing divergent motion at Iceland
- Compared Iceland, Aleutian Islands, and Chile to Axial

Day 6 Objective: Incorporate the pattern of earthquakes in the explanation of Axial

- Revised models based on evidence

Table 2 (continued)

- Exit ticket: under the sea

<u>Day 7 Objective:</u> Relate the heat flow to the location of plate boundaries

- Used maps of the ocean floor to identify Mid-Atlantic ridge
- Created chart diagramming & describing the type of plate motion
- Discovered the relationship between heat flow and plate boundaries
- Considered evidence from heat flow to Revise model
- Exit ticket: evaluating evidence

<u>Day 8 Objective:</u> Explain what might be happening inside the earth to cause plates to move

- Used convection fluid to model heat in Earth's interior
- Answered reflection questions

<u>Day 9 Objective:</u> Demonstrate the use of the MEL in evaluating models of Mid-Atlantic Ridge

- Compared evidence to model
- Created symbols for support and contradict (arrows)

<u>Day 10 Objective:</u> Critique models of Axial

- Presented models
- Reviewed models by peer groups
- Revised models

<u>Day 11 Objective:</u> Test the models of Axial

- Used secondary data from another location (East Africa) to explain Axial

Wrote final explanation with scaffold

To aid the students in following along with the learning activities, we created an evidence summary table to keep in their notebooks and in a poster in the classroom. This evidence summary table was used to compare three models in the Model-Evidence-Link (MEL) matrix (Rinehart, Duncan & Chinn, 2014) discussed below in instructional procedure. The three models were evaluated against six evidence statements. Students had practice using the MEL in a reasoning exercise called “Sam Spade” (described below) prior to this unit. Each part of the MEL, the models, evidence and evaluations, are described in the context of the assignment.

Models. In Round 1, the models were standard diagrams of a divergent plate boundary differentiated by the material at the gap between two plates. All three diagrams showed two blocks above a larger block with a separation between them. The bottom, larger block was labeled “Earth’s interior.” The two separated blocks were labeled “Plate A” and “Plate B” and had each had an arrow pointed away from the middle. In between the two blocks, a shaded area was labeled with a different materials. Model A had loose rock, Model B had new plate material and Model C had water. The middle material in Model A and C were shaded a different color and had a line separating the middle material from the bottom layer. The middle material in Model B had the same shading as the bottom layer with no separation. This MEL (Figure 5) uses the three models of sea-floor spreading as the column headings and six types of evidence as the row labels.

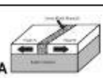
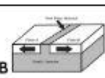
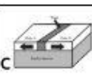
Evidence at Axial	A 	B 	C 
Earthquakes: Cluster of shallow earthquakes			
Age of sea-floor: younger/newer rock			
Topography: higher than surrounding sea floor, lower valley in middle			
Volcanoes: On ocean floor			
Heat flow: highest surface heat flow is along divergent plate boundaries			
GPS (vectors): Plates diverging about 2.5 centimeters per year.			

Figure 5. MEL Matrix Round 1

In Round 2, the models were student-generated. I solicited student ideas to explain what was happening beneath the Earth's surface to create an undersea volcano off the coast of Oregon, Axial seamount. These diagrams had variations not only in the material at the plate boundary, but also in the material beneath the ocean floor and the mechanisms that were causing the spreading. The students used model conventions including arrows, labels and legends. All three models showed a triangle with lines up and out of the top. Model B labeled this shape "volcanoes and mountains." None of the models labeled the material coming out. Model A and C labeled the blocks on either side of the triangle "plates" while Model B labeled them "oceanic crust." Models A and B used arrows on those blocks to show direction of movement. Model A showed the arrows pointing towards each other and Model B showed arrows pointing away. Model C used arrows to point to the middle with a caption indicating "plates" and "moving apart." Model A and B both included earthquakes or seismic activity. Model C labeled a "valley (rift)" and "friction" and "pressure." Model B and C both included a label for what was "pushing up" from the Earth's interior. Model B says "new rock" and for model C, I added the caption "water pushing up." Model B also included a label for "underwater." These three models are shown in Figure 6. The same six types of evidence were used in both rounds.

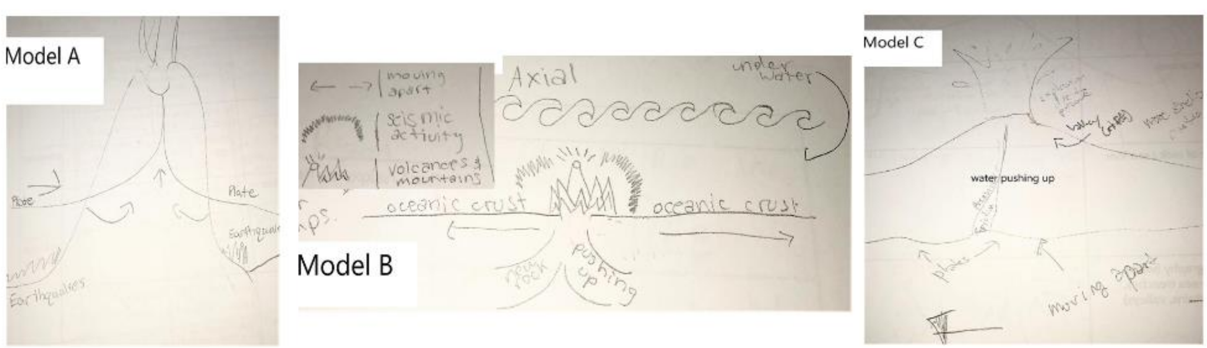


Figure 6. Student Models from Round 2.

Evidence. The same six lines of evidence were used in both rounds. The evidence was introduced over five days using maps and videos and discussion. Students made observations about the Axial seamount and I led discussion to clarify and build consensus. The observations were summarized into “evidence statements.” A brief video that showed lava oozing out of the sea floor led to our working definition of an underwater volcano. We marked Axial on a map and referred to it as “off of the coast of Oregon in the Pacific Northwest.”

After we learned that earthquakes and volcanoes can indicate boundaries between plates, we noticed that earthquakes occurred around the Axial seamount. We examined how far below the surface the earthquakes started (in geologic terms, the “focus”) found that they originated less than 33 kilometers below the surface. We contrasted the depth of these earthquakes to other locations such as those near the Himalayas, the Aleutian Islands and the west coast of South America. In two of those places, the Aleutians and South America, the origin of the earthquakes varied in depth from 33 kilometers below the surface to 200 kilometers. We visualized how earthquakes at a subduction zone, where two plates move towards each other and one plate slides under another, would cause a pattern of earthquakes where they were relatively shallow on one side and deeper on the other. The third location, the Himalayas, also had earthquakes that were shallow like at Axial, but we noticed that the Himalayas are not at the bottom of the ocean. We described the pattern of earthquake evidence at Axial in an evidence statement. The statement read “most of the earthquakes are not very deep (less than 33 km) and most of the earthquakes are clumped in a thick band in the ocean.” I recorded the evidence statement on a poster in the class and the students created their own summary table in their notebooks. When I distributed the MEL to the students, I used a more concise version: “Earthquakes: cluster of shallow earthquakes.” The evidence summary table is shown in Table X.

We examined a topographic map of the ocean floor and noticed that some places are deeper than others and that there are chains of undersea mountains far from the shore. We defined these as mid-ocean ridges. We also found very low parts of the ocean and defined these as deep-sea trenches. We observed that Axial was not an isolated point, that it was part of a ridge of underwater volcanoes along a line more shallow than the surrounding area. We summarized this as “Volcanoes: Underwater volcanoes along a line that is ridge (less deep/more shallow than the surrounding area)” and on the MEL as “Volcanoes: On ocean floor.” We looked at Axial using Google Earth and wrote an evidence statement that it “rises 700 meters above the mean level of the sea floor and at its highest point, it is about 1400 meters below the sea surface. I summarized this as “Topography: higher than surrounding sea floor, lower valley in middle.” After an introduction to relative age dating of rocks, we observed that the rocks that make up the seafloor vary in age. We correlated the higher parts of mid-ocean ridges with younger rock, and deep sea trenches with older rock. At Axial, we found that the sea floor was less than 10 million years old, and I summarized it in the MEL as “Age of seafloor: younger/newer rock.”

We used Google Earth interfaces to make observations that led to the last two evidence statements about heat flow and GPS vectors. The modules created by the Environmental Literacy and Inquiry Working Group (2020) displayed heat flow on Earth’s surface. I showed the students that higher temperatures and younger rock are found at mid-ocean ridges. The evidence statement was “highest surface heat flow at the plate boundary” and the summary for the MEL was “highest surface heat flow.” We used the UNAVCO GPS Velocity Viewer (2020, June 18) to interpret vectors of plate motion and made an evidence statement: “GPS data shows that the Pacific plate is separating away from the Juan de Fuca plate at a rate of 2.5 cm per year.” The MEL summary was “Plates diverging about 2.5 centimeters per year.”

At the beginning of each class we reviewed the evidence statements on the digital smartboard and the students added to their summary table at the end of each class. This table (Table 3) was the basis for the evidence in the MEL that was distributed to the students.

Table 3

Evidence Summary Table

Type of Evidence	In Class	On MEL
Earthquakes	Most of the earthquakes are not very deep (less than 33 km). Most of the earthquakes are clumped in a thick band in the ocean.	Earthquakes: Cluster of shallow earthquakes
Age of seafloor	0-10 million years old (younger/newer)	Age of sea-floor: younger/newer rock
Topography	Axial is 1400 meters below the surface and about 700 meters from the bottom of the ocean.	higher than surrounding sea floor, lower valley in middle
Volcano	Underwater volcanoes along a line that is ridge (less deep/more shallow than the surrounding area)	On ocean floor
Heat Flow	Highest surface heat flow (occurs) at the plate boundary	highest surface heat flow
GPS (vectors)	GPS data shows that the Pacific plate is separating away from the Juan de Fuca plate at a rate of 2.5 centimeters per year.	Plates diverging about 2.5 centimeters per year.

Links Between Models and Evidence. In each cell of the MEL matrix, students used arrows to indicate whether that evidence strongly supports, supports, contradicts, strongly contradicts or is irrelevant to that motion. In both rounds, student drew their own symbols in the left column. The legend is shown in Figure 7. To introduce the tool to the students, I used it to evaluate the evidence at the Andes mountain range in relation to the accepted subduction zone model. We saw that the pattern of earthquakes and volcanoes are explained by the subduction zone model and used a strongly support arrow in those two cells. We observed a trench and a mountain range, therefore under topography, we put a strongly support arrow. Similarly, GPS evidence showing places moving closer to each other was evidence that strongly supports the subduction zone model.

	Arrow	The evidence <u>supports</u> the model
	Double Arrow	The evidence <u>strongly supports</u> the model
	Crossed Arrow	The evidence <u>contradicts</u> the model
	Double Crossed Arrow	The evidence <u>strongly contradicts</u> the model
	Dashed Arrow	The evidence is <u>irrelevant</u> to the model

Figure 7. Legend for MEL Matrices

For Axial, we had not one model but three. To limit student confusion, I evaluated two lines of evidence first, the evidence from earthquakes and volcanoes. We looked at each of the models to decide if the earthquake evidence supported the model or not. We usually agreed on whether to use a “support” or “contradict” arrow but we there was some dispute when to use “strongly” or “irrelevant”. We found that in Round 1, the earthquake evidence supported both the loose rock model (A) and the new plate material (B), but contradicted the water model (C). The volcano evidence supported only the new plate material (B). An example of a MEL from Round 1 is shown in Figure 8.

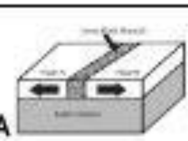
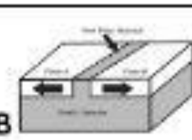
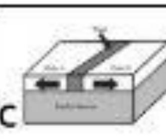
Evidence at Axial	A 	B 	C 
Earthquakes: cluster of shallow earthquakes			
Volcanoes: On ocean floor			

Figure 8. Round 1 MEL

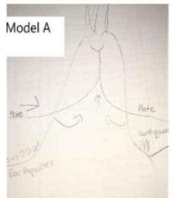
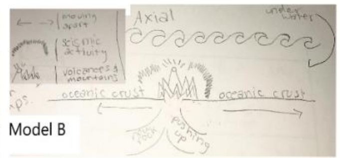
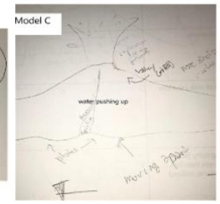
			
Earthquakes: cluster of shallow earthquakes	→	→	→
Age of sea-floor: younger/newer rock	↛	→	↛
Topography: higher than surrounding sea floor, lower valley in middle	→	→	→
Volcano: On ocean floor	→	→	↛
Heat flow: highest surface heat flow	→	→	↛
GPS (vectors): Plates diverging about 2.5 centimeters per year.	↛	→	→

Figure 9. Round 2 MEL

Homework Assignment. The timing of the homework assignment to students was coordinated with announcements to the parents. The information was alternated so that both parents and students were informed and could refer to each other's information. An email to parents was sent on Friday. On Tuesday (Day 7), students were told the assignment would be given on Thursday (Day 9). Students were told that they would have all the information they needed and then they would have until the following Tuesday to record their explanation. On the day the assignment was announced, I gave each student a bright neon colored paper copy of the reference sheet and told them to bring it home along with the MEL. I shared with them the evidence on a Google Slides presentation so they could access that on their Chromebooks. On Friday (Day 10), I sent a reminder email to the parents that the students were expected to complete the assignment by Tuesday. Every day in class I made a general announcement to the class and posted a reminder on the teacher homework webpage. I checked the recordings to see that there were no problems with the sound or other technological errors. I did not check to see how many were recorded with parents so as not to show preference to those who did.

The instructions for the task was for students to record themselves explaining which model they would rule out and why. It required using the Model-Evidence-Link (MEL) matrix (Rinehart, Duncan & Chinn, 2014) that was created through class activities (discussed above). It consisted of three models and six evidence statements and aids students in deciding how strongly the evidence supports each model. Students had practice using the MEL in a reasoning exercise called "Sam Spade" (described below) prior to this unit.

The in-class oral and written homework instructions in both rounds were: "Use Flipgrid to record your reasons for deciding to eliminate or 'rule out' one of the models. Be specific! Use your MEL and cite your reasons." At home, the written directions on the recording app for Round 1 were to use the MEL to describe each model and eliminate one. In Round 2, the at-home instructions on the recording app were longer. The written instructions said: "Use your

Model Evidence Links table to compare each of the three models. What are the weaknesses for each model? Which model would you rule out? Which model is best supported? How would you revise it to make it even better?" On the recording page for use at home, I directed the students to review a slideshow that summarized the evidence and had images of the models that were bigger than the printed handout. In both rounds, the students were given the MEL as an aid to decide which model was not supported by the evidence. After reviewing it in class, I suggested that they take the MEL home. The MEL matrix is organized with models as the column heading and rows for each type of evidence. The models were different in the two rounds, but the evidence was the same.

I encouraged students to complete the assignment by reminding them that there was no penalty for lateness. After the first due date had passed for the Round 1 students, I sent a reminder email to the parents. After this reminder, more students completed the assignment than had completed it on the due date. Because of the closing of the school year, I took different steps to encourage responses from the students in the second round. I monitored responses each morning, reminded students daily in class to complete the assignment and asked them to write the assignment in their daily agenda homework planners. Once the end-of-school-year collection of student Chromebooks was complete, the assignment was closed, and there was no further participation.

Class Resources. To support the students in the learning process, I used scaffolds and protocols that had been practiced since September. These include scaffolds to analyze and interpret data, scaffolds to coordinate evidence and models and scaffolds to foster discussion. Some of these were print documents meant for students to put in their individual notebooks, others were digital, and others were displayed for communal use. Most were provided in multiple formats.

Scaffolds to Analyze Data. A strategy called "What I see, what it means" was used to support students understanding and interpretation of the evidence. Students wrote observations from the maps on small sticky notes, and we analyzed them as a whole class. I challenged students by proposing inaccurate and insufficient evidence and solicited critiques of the data. Summary statements of the evidence were provided as a poster in class for students to use later. Discussions about these statements included evaluation of the quality of the evidence and how it might have been gathered.

WIS/WIM Protocol Poster. Students also used a simple protocol for data analysis that reminded them to look at the title, labels, and legends to see what observations they could make from the chart, table or graph, and then what interpretations they could make from the data. A poster with this protocol was displayed on the classroom wall and a copy was placed in the students' notebooks. The poster describes a "WIS: What I see" as an observation that points to a specific item and restates it in a sentence form. "WIM: What it means" is an interpretation, a way of making sense of the data.

Scaffolds to Foster Discussion. I encouraged students to explain their MEL matrix and the worksheet responses by asking probing questions. Science-specific discussion prompts were generated by students to enhance the general "talk with respect" protocols in use in other subjects. Students wrote their own prompts for their group to use in the categories such as "to agree," "to summarize and support," "to build," and "to make connections." Frequently used prompts such as "Evidence that supports my argument is..." and "One difference between my idea and yours is…" were posted on the walls of the classroom.

Technology Tools. An interactive white board was used to display multimedia content from the web, teacher-created presentations, and student work. The display was touch-enabled and offered digital annotation tools including highlighters. Students used their Chromebooks, school-provided devices that run Google Apps for Education, and Flipgrid, a digital recording program. This program is a typical instructional tool for developing 21st century digital information fluencies. The recording of student oral responses gives teachers a better understanding of student thinking and helps them to design instruction that meets student needs.

Maps. Poster-sized color cartograms of distributions of volcanoes and earthquakes, a map showing the age of the seafloor and a topographic map was available to the students.

Plate Boundary Map. A world map showing major and minor tectonic plates was shown frequently on the white board, displayed on a poster and given to the students on paper.

MEL Poster. A MEL matrix created with sample models from the introduction was displayed in poster-size form on the classroom wall along with the symbols to be used in the columns.

Sam Spade Poster. Prior to this unit, I led students through a two-day investigation of a fictional account of a robbery to help them practice their reasoning. The students were presented with four pieces of evidence and prompted to decide how the evidence supported or contradicted their ideas about the guilt of the accused, Sam Spade. The students' ideas about the incident were discussed as "models" and the evidence was linked to the models with arrows on a MEL matrix. After discussing the four pieces of evidence as a class, we created a consensus version of the MEL matrix and the students were given two more pieces of evidence and asked to decide if which model was better supported by all the evidence. The students recorded their process in a paper handout and kept it in their science notebook. A poster of the consensus MEL remained in the class as a reminder of the use of evidence.

CER Poster. A Claim Evidence Reasoning poster reminded students what each component is supposed to contain. This information was also provided in paper format in student notebooks.

Checklists. These papers and posters encouraged students to self-evaluate their work.

Assessments. Several formative and summative assessments were conducted.

Formative Assessments. Students had two assignments to evaluate models of their peers, on day 3 and day 10. These oral reactions helped assess their understanding of the purpose of scientific models and the underlying concepts. They also had two “exit ticket” assessments, on day 6 and day 7, to determine their understanding of the mechanisms at work in plate tectonics and to evaluate how the evidence fits with their current model. Another formative assessment was the intervention homework assignment designed to explain how one model can be ruled out. Their written classwork and their responses to probing questions were also used to assess understanding.

Summative Assessments. At the end of the unit, students individually wrote an explanation of plate movement, using their MEL, to respond to an anonymous student’s diagram and explanation. The students were told to use the MEL to answer the question: “What could be causing or contributing to the location of the Axial seamount?” The final written explanation was assessed using a standard rubric that measures the use of evidence and reasoning. At the end of the third week, students took a test consisting of 22 questions. The questions targeted the learning objective: Tectonic plates move across Earth’s surface, carrying the continents, creating and destroying ocean basins, producing earthquakes and volcanoes, and forming mountain ranges and plateaus. The questions are shown in Appendix F.

Data Collection

The collected data was used to answer the research questions: (a) What are the features of the guidance (instruction, training, and scaffolds) that facilitate parent-child interactions?; and (b) What talk moves by parents and children are associated with more productive discourse? A summary of the data collection is shown in Table 4.

Table 4

Data Collection

Data	Source	Purpose: research question 1	Purpose: research question 2
Student reflective comments, questions, and suggestions	focus group	Revise design features	
Small group discussions	video recording	Revise instruction	
Explanation of ruling out one model (homework)	video recording	Revise design features	talk moves and productive discourse
Observation of parent/child interactions (homework)	video recording	Revise design features	talk moves and productive discourse
Response to student claim (summative assessment)	written explanation	Revise design features	talk moves and productive discourse
Parent reflective comments, questions, and suggestions.	survey	Revise design features	

Learning Activities and Discussions. The classroom activities were video recorded on the last three days of the unit. The whole-class video recordings for each day were downloaded and named by the title of the lesson. Field notes after every class and at the end of each day recorded the questions that students had and what adjustments to the lesson plan were needed. These notes documented the classroom activities to ensure fair treatment in all classes.

One peer group in each section was video recorded during the last three class periods devoted to small-group discussion about the evidence for different models of plate movement. Each discussion lasted approximately ten minutes. The discussions of all groups were monitored to note student talk about models and evidence. The small group recordings were named with a color (each group's table has a different colored bin), class period, and date. I took notes with the names of participants at each color table for each period and indicated if a student was absent or anything unusual occurred (such as a fire drill).

Other data sources include student responses to assessment questions and written work completed in class individually and in groups, such as the model drawings and reflection questions as discussed in the instructional procedure above.

Student Focus Group. The focus group was conducted with students on the final day of instruction, after they had finished their written explanation, about 6-10 days after the homework was assigned. The questions probed how children delivered the material to their parents and how children used the MEL. Other questions asked about their perceptions of the assignment. The questions were:

1. What did you think of the assignment?
2. Did your parent or another adult ask questions while you did this assignment?
3. If not, why not?
4. What advice would you give to another student who would do this activity?
5. In what way was this activity helpful to you?

The focus group was recorded. The students tended to talk over one another and a few louder children expressed their view while many others were quiet. I followed up later at each table to hear from the students who did not volunteer during the whole group discussion.

Student Explanations. The students had two opportunities to use the MEL to argue for or against a model. The first homework assignment, in which parents were invited to participate, required the students to record their reasons for ruling out one model. This was an oral response using Flipgrid, set to private, so only the teacher can view it and each student must generate an original response. The second opportunity was a summative assessment, on which students were directed to use their MEL to respond to an anonymous student's diagram and explanation. The prompt was: "This is the work of a student who examined the Axial seamount. How would you respond to this claim? 'At mid-ocean ridges, water fills the empty space between two plates?' What evidence would you use to contradict this idea?"

Parent Survey. The parent survey was delivered via email and included questions about their experiences with the intervention. Questions were:

1. Please indicate whether you agree or disagree with these three statements.

   My child and I enjoyed this task.

   My child seemed to understand the content of this assignment.

   This activity helped me understand what my child is learning in school.
2. How does this activity correspond with your own memories of middle school science?
3. Is there anything else that you want to tell me about this activity?
4. What language do you most often use with your student?
5. Do you work now or in the past in a science field?

Responses in Round 1

Following the first round of the intervention, an analysis of the use of the instruction, training, and scaffolds provided a foundation to revise the guidance for the second round. I was interested in whether the students completed the assignment, and if not, why not. I kept a record of the students who had submitted a recording and followed up with the students who had not. I asked them whether they had trouble accessing the assignment, if they had the materials they needed and offered suggestions on how to get started. Most students said they would do the assignment. To avoid pressuring students to participate, I did not ask them to reveal whether they had worked with an adult. After the first due date, nineteen students had made recordings. The first fifteen responses were from students on their own. Because only three parents had participated in the first set of recordings, I sent an email reminder to all parents about the homework assignment. One week after the due date nineteen additional students recorded, six of them with parents. In total, 41 of the students in the Round 1 classes participated, nine of them with parents. The responses of participants is shown in Table 5.

Table 5

Number, Length and Type of Recordings From Round 1 Participants

With parent or other adult		Without parent or other adult	
number	length (in minutes)	number	length (in minutes)
9	1 minute 54 seconds	32	0 minutes 39 seconds

My first impression of the recordings was that they were shorter than I expected. Most were less than one minute. I compared the recordings of the students with and without parent participation and found that the parent recordings were longer. I noticed that one of the longest, most detailed responses included the preface "guess you answered that question prior to starting this interview. I also asked…what exactly the models were. That way I had a little idea of what exactly she was doing…" This dialogue resulted in the addition of this prompt to the Round 2 guidance: "Tell me about the models." Longer, more elaborate responses from students were evoked by parents in Round 1 making up their own questions. These questions were used to develop new suggested prompts and I changed the title of the page from “Questions” to “Conversation Starters.” The instructions to the parents were changed from: “Help your child explain why they will rule out one of the models as a possible explanation for the Axial volcano.” In Round 2, the instructions were to help students compare the models and decide which one is best supported.

Analysis of Responses in Both Rounds

The recordings submitted through Flipgrid were counted and showed that 74 students out of 95 completed the assignment, a participation rate of 78%. For comparison, a similar assignment from a month prior to the study resulted in 62 students submitting recordings, a participation rate of 65%.

The recordings were transcribed by an automated service. I compared the transcriptions to the audio file to fill in missing words and correct mistakes. I removed student names and uploaded the text documents to Dedoose. The students’ completed assignments are called “responses.”

After the completion of the second round, analyses of the text transcriptions of the responses were conducted using two separate and independent coding schemes. The first was an analysis of the use of the guidance for which I used the adult and child questions and answers as the unit of analysis. The second was an analysis of the student statements and how they formed a coherent explanation. I will explain the procedure for both and then explain how they are independent.

Analyses for Use of Guidance

The purpose of the first analysis was to determine how the guidance was used. The responses of the 21 students who had an adult partner were reviewed, and a coding scheme was developed. I used the adult and child questions and answers as the unit of analysis.

Parent Talk. Adult utterances were segmented by phrase or turn-taking based on when an adult began speaking and stopped speaking. In some cases it was necessary to go back to the recording to be sure to include the entire adult utterance when it was interrupted by a student comment. These statements were generally short, fewer than twelve words. The parent turns sometimes included more than one phrase. Phrases were sorted into three broad types: questions from the instructions, other questions and other statements.

When the adults used the questions or prompts from the guidance, I coded the statement as “recite question from instructions.” I also made a subcategory called “with modification” for instances where the question was substantially the same as the instructions but with a modifier such as “based on what you learned” or “can you tell me about the three models” instead of “tell me about the models”.

I used an inductive process to create a coding scheme for the other questions and statements, which resulted in seven other codes. The parent turns were all coded independently, one code applied to each turn. The coding scheme for adult statements is shown in table 6.

Some of the other questions referred to the MEL. These phrases were coded by the part of the MEL they were referencing. There were questions about the diagrams at the top of the MEL, “Okay. So all three of these are Axial.” These were coded as “questions: models.” There were also questions that asked for evidence: “What evidence strongly contradicts the model C?” which were coded as “question: evidence.” Other questions asked about how the evidence supported or contradicted the models. These questions asked about the arrows, such as "“talk to me about the row with supports arrows for the two models. That means that the evidence could support both models?" or "is that what the double Arrow versus single Arrow means?" These were coded as "question: coordinating."

Table 6

Coding Scheme for Parent Statements

Code	Description	Example
Recite question from instructions	Questions or prompts that were suggested by the intervention's guidance	"How would you revise it to make it even better"
Question: Models	Asking to identify or describe features of the diagrams at the top of the MEL	"Okay. So all three of these are axial."
Question: Evidence	Asking to identify or describe the rows (lines of evidence)	"What evidence strongly contradict the model C?"
Question: Coordinating	Asking about the relationship between the evidence and the model (supporting or contradicting)	"So heat surface flow is shown in which model? Any of them?"
Direction/Procedure	Asking or giving directions about the procedure for the assignment	"Did your teacher draw this or did you guys draw"
Clarify	Repeating or rewording student statement, in question or statement form	"So that's why for models A and C were the best for the topography category and then the age of the sea floor model a doesn't help you at all."
New idea	Contributing an idea or term that student has not used yet.	"Are those also tectonic?"
Approval/Praise	Phrases that encourage student to continue	"Ok" or "right" or "good"

Other types of statements were those questions related to the in-class activities or the at-home assignment, such as: "Did your teacher draw this or did you guys draw?" or "how did you guys go over this in class?" These were coded as "direction/procedure." There were also statements where parents repeated, rephrased, or summarized what a student said. I coded these as "clarify" if they used the same terms as the student. This includes a parent who said, "Is that what the double arrow versus single arrow means?" and a parent asking for a definition of a term the student used. There were also conversational cues like "ok" or "good" that were coded as "approval/praise."

I coded some statement as "new idea" if the parent used a new term like "magma" or ideas that the student had not expressed, for example, "Also, you could infer the heat flow part, right?" These questions or statements "magma," or "heat flow" pointed students to some important feature that the parents did not hear the student explain. These statements were different from general questions because they show that the parent is using the information on the MEL. Some questions asked students to address a model that they had skipped, e.g., by saying, "okay, how about model C?" Some questions were about missing a line of evidence ("So heat surface flow is shown in which model?") I coded these separately from the Model or Evidence questions because they did not ask students to elaborate or clarify their ideas but introduced new ones that students had not talked about yet. Some of these statements contained specific hints to the students about the relationships in the MEL rather than general questions like "what does the model show?" Others of these "new ideas" were questions that referred to experiences outside the classroom such as "do you know how to say volcano in Spanish?"

Analysis for Parent Approaches

I coded all of the parent talk to identify the parent approaches that were effective at drawing out student ideas. Some parents used only the suggested questions while others added or skipped questions. The additional questions were varied. Some parents reworded the suggested questions. Parents also repeated the student's words or rephrased their answer to ask a specific follow up question. Others added new ideas or encouraged students to evaluate evidence. Other parents repeatedly tried different prompts: “So can you draw some of the pictures?” and “Can you give me some examples of maybe a country or state?”

Adults asking extensive questions might help the student communicate their understanding. This approach will be called active questioning. The approach of parents who used only the suggested questions will be called directed questioning.

Analysis of Student Talk

The student utterances were coded using a similar process. Student talk turns tended to be longer than adult utterances and expressed multiple ideas. I segmented student talk into phrases and when possible coded each phrase independently. When it was not possible, a statement was coded in multiple categories. For example, one student said, “Model C is better supported because it shows water pushing up instead of magma.” This statement was coded as both model talk and as coordinating talk. The first part of the statement, “Model C” is a reference to the diagrams at the top, and the second phrase “water pushing up” refers to that model, but the third part “instead of magma” refers to one of the evidence statements. Because the students tend to combine their thoughts and circle back to the same idea, coding the phrases independently would obscure the complexity of their thinking. The “instead of” phrase is doing the work of coordinating, and while it is not a complete scientifically accurate statement, it is clear that the student understands the inaccuracy of the model.

Using an inductive process, I coded all student statements and found that students talked about models, evidence, and arrows. They roughly correspond to the parts of the MEL.

Model Talk. After reviewing all the segments in the describing models category, I developed codes for the phrases where students identified features of the diagrams, elaborated on a single model by describing features that were implied but not visible, identified features that they expected to see but were missing, and stated differences between models. The diagrams purposefully allowed interpretation, therefore, I did not distinguish between accurate and inaccurate observations. These codes are presented in Table 7.

I coded statements that described parts of the model as “identifications.” Some students summarized features they saw and also made inferences about features or mechanisms that did not appear. These statements were coded as “elaborations.” Because students who elaborated also summarized the features they saw, the “elaborations” code coincided with the “identifications” code. An example of an “elaborations” statement was when a student makes an inference about a feature that the diagram does not identify with a caption or label. An example of an inference was when students described oceanic or continental crust, which did not appear in the diagrams. An example of a statement that both identified parts and made an inference is: “Model C is that in the space between two plates at an underwater divergent plate boundary, there was water there.”

Some statements that identified parts of the diagram also identified weaknesses of the model. The students described features that were missing or inaccurate: “Model C also doesn't show really show an ocean floor and we could see the rift and valley, but it's not really pointing to the correct spot.” These statements were coded “weaknesses.” Some statements also compared one model to the other to find similarities, for example, in direction of motion. These statements were coded “similarities.” Students also contrasted models to identify differences in materials or topographic features. These statements were coded as “differences.”

Table 7

Student Model Talk

Code	Description	Example
Identifications	Pointing out parts of the model such as “loose rock” “new rock” and/or “water;” or “underwater”	“Model A is loose or Old Rock. Model B is solid rock and Model C is water.”
Elaborations	Describing the diagram by inferring unseen features or mechanisms such as “earthquakes/seismic activity” “moving apart,” “molten rock,” “crust,” and/or “valley.”	“Model C is that in the space between two plates at an underwater divergent plate boundary, there was water there”
Weaknesses	Describing missing or inaccurate features such as “heat flow,” “magma,” “crust,” and/or “rift.”	“Model C also doesn't show really show an ocean floor and we could see the that rift and valley, but it's not really pointing to the correct spot.”
Similarities	Comparing one model to the other to find common features	“It also shows that, um, there's newer rock pushing up to form the volcano like model C or A.”
Differences	Contrasting one model to the other to find differences	“I decided to eliminate model C since there's just water in the middle and model A has loose rock in the middle”

Evidence Talk. Students engaged in evidence talk by stating or summarizing the lines of evidence to the model. These statements were coded as “using evidence.” To indicate differences in the detail used by the student, these statements were attributed a quality rating: “low” or “high.” Low quality use of evidence repeated the information as it appeared on the guidance and did not make an interpretation or application. An example is: “We looked at topography, the age of the sea floor, heat flow and the GPS vectors.” High quality evidence talk added phrases that did not appear on the guidance. These statements might include a student definition or interpretation. For example, instead of saying “topography” or “elevation,” a student said "volcano is higher than the surrounding sea floor." I also labeled the use of evidence if it was inaccurate. Inaccurate use of evidence was seen when a student stated that seismic activity would not occur near a volcano or when a student explained that high heat flow indicated a convergent boundary. The coding scheme for evidence talk is shown in Table 8.

Table 8

Student Evidence Talk

Code	Description	Example
Use of evidence – low quality	Stating the lines of evidence that appear on the guidance.	"We looked at topography, the age of the sea floor, heat flow and the GPS vectors."
Use of evidence – high quality	Defining terms or summarizes the lines of evidence by using phrases or words that do not appear on the guidance.	"volcano is higher than the surrounding sea floor" "and in GPS vectors I see that in model B the oceanic crust, the plates are moving away from each other"
Use of evidence – inaccurate	Wrongly describing evidence from the information given	"doesn't show the right areas of seismic activity besides…around and under the oceanic crust"

I also distinguished between accurate and inaccurate talk about the evidence. Some students used the terms "pressure" and "friction" as if they were visible or that earthquakes were the cause of plate motion. Other students wrongly thought that the material at a plate boundary was crumbled rock or water. They also misunderstood the heat flow at a plate boundary: "I think heat flow supports Model A the best because the middle is loose rock. The heat from Earth's interior easily goes through the loose rock."

Coordinating Models and Evidence. Students also talked about the arrows they used, why they used them and how the evidence relates to the models. This talk was coded as "coordinating" talk. Statements in this category overlapped with model talk and evidence talk but included some link or connection between the two. Sometimes they described part of the model first, other times they used evidence statements first. The linking phrases were varied but commonly included the word “because.” Coordinating talk was the student giving reasons or explaining rationales for the students’ preference for one model over another. The level of detail in the coordinating statements was used to assign a quality rating of “high,” “medium” or “low.” These statements were also coded if they were inaccurate. Table 9 shows the coding scheme for this talk.

Table 9

Coordinating talk

Code	Description	Example
Coordinating talk – low	Identifying supports arrows or contradicts arrows in any one column as it relates to a model.	“There are all supporting arrows with model B.”
Coordinating talk – medium	Describing how the evidence applies to two or more of the models, or describes how the evidence is stronger for one model than another.	“Model C is better supported than model A because it has more supporting arrows and less contradicting arrows.”
Coordinating talk – high	Expressing the relationship between the body of evidence and a model to explain how a model can be ruled out or is the best fit.	“But the piece of evidence that I think contradicts Model C the strongest is that earthquakes, because earthquakes happen on land and not in water, and it just shows water in the middle while for the other two models earthquakes supports.”
Inaccurate coordinating talk	Reasoning incorrectly about observations from the evidence.	“The heat from Earth's interior easily goes through the loose rock.”

Low quality coordinating statements reported which arrows were used: “supports” or “contradicts” or “irrelevant.” An example is: “Models C and A, there, some are relevant arrows and some contradicting and strongly contradicting arrows.” Other low quality statements were referred to one model without giving reasons: “in my opinion, the best supported model would be model B.”

Medium quality statements compared how the evidence applied to two or more of the models. For example, one student explained that only one model was supported by the GPS evidence. The medium-quality code was also used for statements that quantified the evidence by counting the number of supports arrows. One student declared one model best supported because it had more supports arrows. Another declared it was best because it had no contradicts arrows. “Model C is better supported than Model A because it has more supporting arrows and less contradicting arrows.” The words “more” and “less” show that the student has compared the types of arrows used in Model C to the arrows for Model A. Medium quality statements also reference how the student gave one line of evidence more weight by explaining the use of a “strongly supported” rather than a “supports” arrow. An example of this type of statement is: “Model C is better supported and I believe it's better supported because it has a very strongly supported topographic evidence.”

High quality statements explains how the arrows are used to weigh more than one line of evidence against one model or to evaluate the strengths and weaknesses of the models. These statements refer to the body of evidence for one model compared to the body of evidence for another model. An example is: “Model C is better supported … because it has a very strongly supported topography evidence and evidence that it shows age of seafloor…because it has very supported heat flow evidence and it has some very super strongly supported GPS vectors.”

Another type of high quality talk referred not only to the type of arrow but the evidence that it represents, for example: “the piece of evidence that I think contradicts model C the strongest is that earthquakes, because earthquakes happen on land and not in water, and it just shows water in the middle…” In this example, the word “strongest” means that the student compared the earthquake evidence to the other lines of evidence and gave that more weight in ruling out Model C.

Other Student Talk. Other types of student talk were questions, restatements of parent ideas, and talk about the process of the assignment. These codes were applied to talk that was not coded as models, evidence or coordinating talk. This type of talk is shown in Table 10. All student talk was coded using one of the categories described here.

Table 10

Other student talk

Code	Description	Example
Student question	Expressing a question about something the parent said, a request for information	“For all of three of them?”
Student restating parent idea	Following a parent idea, uses similar words to confirm what the parent said	“They're different theories.”
Student stating procedure	Offers information about the process in response to a parent “what” “how” or “why” question.	“Yeah, because I need to make sure all my answers are correct”

The analytical method described above focuses on how parent questions relied on the suggested questions and how the students used the parts of the MEL, the models, the evidence and the arrows to answer those questions. In the next section, I will describe a second approach that was used to evaluate how productivity of the talk.

Analysis for Productive Discourse

A separate analysis was needed to determine what talk moves by parents and children were associated with more productive discourse. To establish the characteristics of productive discourse, I reviewed the responses of the twenty-one students who had an adult partner. I used the word “response” to mean all of the student talk in one recording. Various measures of talk quality were considered before I settled using on a deductive method to code the student's talk. This analysis allowed me to consider each student's response as a scientific explanation and evaluate how strong or weak it is as an indicator of whether the parent-child interaction was associated with productive discourse.

I considered evaluating the quality of each student's talk based on quantifiable criteria. For example, I might consider a response high quality if the student expressed three different ideas in different categories, such as describing the model, describing the evidence, and coordinating talk about models and evidence. I might also consider a response high quality if there was a high word count recorded. After consideration, I observed that some students did do all of these--describing the model, describing the evidence, and coordinating the evidence and models, and using a lot of words, but their response still fell short of a coherent explanation.

One team of researchers, Kelly and Takao (2002), developed an argumentation analysis model that offers a way to evaluate the quality of the oral responses. The model was developed for undergraduate geology students' written explanations; therefore, it requires adaptation for use in this study, because the level of knowledge is quite different in the younger students in this study. In addition, the number of identified statements in oral explanations can vary based on student's conversational style. With these differences in mind, I developed a coding scheme in a similar format to break down the student talk and classify the fragments of talk in order to evaluate the response as a whole.

Takao and Kelly (2003) used the term "propositions" to describe the sentences or expressions that they sorted into epistemic levels. In this study, because these students are giving their explanation orally and there is no punctuation to mark the end of a sentence, segmenting the student talk into propositions was a challenge. I use "statement" to indicate one turn of speech. A statement might be a sentence fragment or phrase, but it could also be several sentences together. The statement begins when the student starts talking and ends when the parent asks a question or otherwise begins talking. In the Takao and Kelly work, a single proposition might be assigned to more than one level, often because students wrote a compound sentence. Therefore, I also allowed applying more than one code to a statement.

The student statements were grouped and classified based on their references to the diagram or model, the location, the data or evidence statements, or the geological concepts we read about or discussed in class. These references represent a range of ideas from the visible, as in the diagrams, to the theoretical, as in a divergent plate boundary. In Takao and Kelly, the range of ideas was placed in an order called epistemic levels.

The Takao and Kelly argument analysis model classifies the student statements into six epistemic levels, from references grounded in data to abstract theory. These levels are: "representations of data, identification of topographical features, relational aspects of geological structures, data illustrations of geological theories or models, geological theory or model proposed by the author, description of geological processes and references to definitions, experts, and textbooks" (Takao & Kelly, 2003, p. 349). In this study, the student talk also included references to data and theory. Based on this similarity, I devised a similar order of epistemic levels for the talk of the sixth grade students (Table 11).

The order of epistemic levels in the explanations seen here ranges from talk that is specific to the given diagrams or the location (Axial seamount) to general geological concepts, terms or processes that the student read in a text or heard about in class discussion. I used 6 levels, with Level I being the most specific and Level VI being the most general.

When the students referred to the diagrams (A, B, or C) or the location (Axial) without using a geologic concept, event or process, I coded it as a Level I statement. When the student identified a topographical feature, like a rift, or used data about geological events, like the number of earthquakes, I coded it as a Level II statement. Level III was applied when a student declared a relationship between two or more landforms or events at a specific location. Level IV was applied when a student explained a relationship between the evidence and a geological concept, without referencing the specific location. A Level IV statement might use the model to explain how the geological event could occur, implying that the model explains locations other than Axial. Level V was applied to statements that expressed the student's own ideas about geological processes but did not reference the location, the specific observations or the given diagrams. Level VI statements referred to geological processes or terms from classroom discussion without relating the concept to the models or the location. There were also inaccurate statements which were coded separately.

The student statements at Level I & II are specific to the location under consideration, or the given data and diagrams, while Level V & VI are general and could be understood without knowing the location or seeing the diagrams. Levels III & IV are statements that connect the observations to the location or to the models, or provide evidence for the theory. Kelly and Takao emphasized that higher levels are not in themselves an indicator of quality. Instead, a strong argument will use statements at a range of levels. In Takao and Kelly (2003), a high scoring paper included propositions distributed across the various epistemic levels, with many at Level II, II and IV. A low-scoring paper had a majority of propositions classified at one end of the range, in epistemic Levels V or VI. The mid-level propositions were absent and the argument lacked supporting evidence. In the next chapter, I explain how I used the frequency of the statements at each level to assess the strength of the argument.

Table 11

Description and Examples of Statements by Epistemic Level

Level	Description	Example
VI	Defining geologic processes (magma, convergent) using text or class notes, not related to a specific location.	"…It all starts from the oceanic crust. It pulls apart the molten rock and magma pushes up to create the volcano."
V	Explaining geological processes or a model of a plate boundary in own words rather than standard scientific terms, not specific to the location.	"Also, you can picture it like this is a one hand we can let, we can label this pressure and this hand, we can label it friction. These two are gonna rub against each other and once there's enough pressure, the volcano is going to be forced to explode"
IV	Using data to explain geological events (volcanoes/shallow earthquakes, divergent/volcano) as represented by a model, not specific to the location	"Model A, was not eliminated because it does show clusters of shallow earthquakes. It does show the age of the sea floor and it has GPS vectors, which are plates diverging about 2.5 centimeters"
III	Expressing relationship between two geological events or landforms (volcanoes/trenches, depth of earthquakes, molten rock) specific to the location	"And then what happens is their seismic activity there. So, so after the volcano there could be an earthquake or even before the volcano there could be an earthquake"
II	Identifying topographical features or events from the data (earthquakes)	"Model B shows, oceanic crust a flat, oceanic crust layer."
I	Referring to the diagrams (Model A, B, or C) or the location (Axial)	"It's because it has loose rock material inside it and it, none of the evidence is strongly contradicts model A"
X	Inaccurate statement	"It could also form a volcano and water will shoot out of it because all the water from the mountain, um, will come out of the mountain or volcano"

Independence of Analyses

I used two independent coding schemes to conduct the analysis. The purpose of the first scheme was to explore the types of statements the students made and how those statements were related to the guidance, specifically the suggested prompts and the MEL. The second scheme was used to determine if these statements were productive, if the students produced a thorough and coherent explanation. I determined that the schemes were independent by comparing the whether all statements in one category in the first scheme would be coded in the same category of the second scheme. This was not the case. Except for statements that were coded model talk--identification, which were usually coded in Level I, how statements were coded in the first scheme did not determine which category they were coded in the second. Evidence talk is an example. Regardless of the quality (high, medium or low), an evidence statement could be Level III, IV or V. If a student made a comparative statement, for example "I believe the most useful evidence is, um, is, is probably the heat flow," it was coded Level III, because it evaluated two or more pieces of geological evidence at the location. An evidence statement was coded Level IV when a student explained a relationship between the evidence and a geological concept, for example GPS vectors and a divergent (moving apart) plate boundary "… there is a heat flow in that space of water and the GPS vectors, um, all model C, also supports it because the plates are moving apart at the bottom. A Level V evidence statement was about general geological theory such as the occurrence of seismic activity: "Earthquakes support model B because … earthquakes are basically the movement of the plates." The definition and application of codes the first scheme were not related to the codes in the second scheme.

Reliability and Validity

The coding of the responses was conducted exclusively by the researcher. After I coded all of the talk, I compared the statements in each code side by side to the other statements in the category and to code's description. I verified that I applied the codes consistently and accurately. A second coder was trained in the coding scheme and asked to code independently as a reliability check. I used the inter-rater-reliability tests on the research tool Dedoose (dedoose.com) that calculates a Pooled Kappa (https://www.dedoose.com/blog/inter-rater-reliability, de Vries, Elliott, Kanouse, & Teleki, 2008) as an overall measure for tests with more than one code. The Pooled Kappa is based on Cohen's kappa, an assessment of inter-rater agreement (Cohen, 1960).

The second coder coded 47 excerpts, representing 15% of both parent and student statements, from three transcripts, representing 14% of the recordings. Initially, the coders were in agreement for about 50% of the codes from the model/evidence/coordinating scheme. After discussion and explanation, a second set of 16 excerpts were coded with 73% agreement. The second scheme with the epistemic level codes was tested the same way, using 22 excerpts, representing 12% of the 197 statements. Initially, the coders agreed on 46% of the statements, with higher percentages for Levels I and VI and lower agreement at Levels II, III, IV and V. After discussion, another set of 18 statements were coded with 79% agreement. These Pooled Kappa scores of 73% & 79% are considered good (Landis & Koch, 1977) or "excellent" (Cicchetti, 1994).

CHAPTER FOUR: FINDINGS

In the previous chapter, I described the design and implementation of the instruction and research. In this chapter, I characterize parent approaches and student talk. I identify patterns to understand how the guidance was used and what talk moves are associated with higher quality responses. The research questions are:

- What are the features of the guidance (instruction, training, and scaffolds) that facilitate parent-child interactions?
- What talk moves by parents and children are associated with more productive discourse?

The results described below indicate that there were differences in how the guidance was used and that the two forms of the guidance was associated with different patterns of parent-child interactions. Two features of the guidance that are relevant to these findings were the suggested questions and the source of the models that were discussed.

Observed differences in the use of suggested questions led to the description of two parent approaches: active questioning, defined as parents who supplemented the suggested questions with their own and directed questioning, defined as parents who used only the suggested questions. More parents in Round 1 took the directed questioning approach and more parents in Round 2 took the active questioning approach.

Differences in the responses were observed in the two rounds. The recordings in Round 2 were longer and included more talk overall and more of each type of talk. Students in Round 2 were more likely to use model talk and used more model talk than Round 1 students. This may be related to the models being student-generated rather than standard diagrams.

I developed a measure of response quality that points to a relationship between parent approach and productive discourse. One important element of a high-quality response was a number of statements that link the observations to the theory or evidence to the models. These statements were numerous and nineteen of the twenty-one students used them. This is attributable to the instructions to focus on linking data to models. A second element of a high-quality response was the range of types of statements, called epistemic levels. Students in Round 2 used more levels of statements and there was a significant difference in the mean number of levels. A third element was the number of statements used in a response, and again, there were more statements in Round 2 than Round 1 and students in Round 2 used more on average than students in Round 1. Using these criteria, I found that there were more responses from Round 2 that represented high-quality responses. Fourteen of the 21 responses were high-quality and eleven were from Round 2. High-quality responses were significantly related to Round 2.

Two of these criteria were significantly different between the responses of students whose parents used an active questioning approach and those who used directed questioning approach. The students who had a parent use an active questioning approach had more statements and a higher number of levels. The percentage of active questioning responses that were high-quality was 82%, while 50% of the directed questioning responses were high-quality. The results of these three measures suggests that active questioning by a parent is related to stronger argument by the student. The combination of the different questions, the different models and the active questioning approach may be responsible for the higher quality responses in Round 2.

Recordings Submitted by Students with Parents

The students were assigned the task of choosing a model that explains what happened inside the Earth to form the Axial seamount, an underwater volcano off the coast of Oregon. They completed the assignment by recording their response through an online program accessed through their school issued Chromebooks. The recordings were counted and showed that 74 students out of 95 completed the assignment, a participation rate of 78%. For comparison, a similar assignment from a month prior resulted in 62 students submitting responses, a participation rate of 65%.

Students were asked about their experiences immediately after their assignment was due. The questions were intended to identify weaknesses in the design of the MEL and the assignment and misunderstandings that could be avoided for Round 2. Students' answers to the questions were not useful. To the questions, "what did you think of the assignment?" and "in what way was this activity helpful to you?" students responded with shrugs or "nothing." The responses to the question, "what advice would you give to another student who would do this activity?" were similar. When I asked, "Did your parent or another adult ask questions while you did this assignment?" and "why not?" more students answered. Several students stated that it was because they did not need or want parent help. One student shrugged, saying, "I didn't want to ask." Another student said, "I knew I could do it by myself." Several students said that parents would make it take too long. One student said, "My mom always takes something that should take five minutes and it takes an hour." Other students stated that time was a limiting factor. One student said, "My mom is too busy." Another student said that her mother got home from work too late. Others said their parents work schedules or travel prevented them from participating. The findings from the focus group were limited to reasons why students did not have parent assistance.

There were differences in the participant characteristics between Round 1 and Round 2. While Round 1 had more students participating, there were fewer who had parents or other adults asking questions. There were 48 students in the classes that were part of Round 1 and 47 students in Round 2. The number of students who completed the assignment from Round 1 classes was 41 (88% of the students) and from Round 2, 33 (70% of the students). Nine of the 41 students from Round 1 classes and 12 of the 33 students from Round 2 classes recorded a response with an adult.

The adult participants were sometimes identified by the student as “mom” or “dad” or “my sister.” In other recordings, I could identify the adult as a parent based on past interactions with the parent in school on the phone. In the few cases where the relationship was not specified I did not assume the adult was a parent.

The recordings from Round 1 and Round 2 were also different in length. The Round 1 recordings ran shorter. The mean length of recording for the Round 1 students without their parents was 39 seconds. The mean length was 1 minute 54 seconds for students who recorded with an adult. The Round 2 recordings both with and without parents were longer. The mean length of the recordings without an adult was 3 minutes 6 seconds, and for recordings with an adult the mean length was 4 minutes 15 seconds. Table 12 shows the distribution and length of recordings in each round.

Table 12

Number of Participants and Length of Recordings in Each Round

	With parent or other adult		Without parent or other adult	
	number	length (in minutes)	number	length (in minutes)
Round 1	9	1 minute 54 seconds	32	0 minutes 39 seconds
Round 2	12	4 minutes 15 seconds	21	3 minutes 6 seconds

Changes in the intervention which were intended to have an effect on the content of the discussion may have indirectly resulted in the differences in the length of the recordings and the parent participation. Three aspects of the intervention may be relevant: the instruction, training, and scaffolds. The instruction was the presentation of the assignment to the students, the training was the video presented to the adults, and the scaffolds were the MEL and the questions suggested to the adults. I will describe the observed differences in the discussions and explain how changes from Round 1 to Round 2 of the intervention may account for those differences.

Parent Use of Suggested Questions

One change between Round 1 and Round 2 was in the suggested questions. I coded all the parent questions from both rounds. These included the suggested questions and other questions that parents used. I counted the number of recordings in which each question was asked. The results are shown in Table 13. The questions that were not suggested by me—such as "What does it have inside the two plates?" or "what else do you learn in the class about the models?"—were coded as "other" questions/statements; these are discussed in the following section. The results show that all 9 parents in Round 1 used the first question, and at least two of the next five questions, but only 2 parents (22%) used all of the questions. All 12 parents in Round 2 used the first two questions, 10 of them used another question and 8 used a fourth suggested question. 66% of the parents in Round 2 used the all of suggested questions. Parents in Round 2 used more of the suggested questions.

Table 13

Use of Questions in Each Round

Round 1	Count	Round 2	Count
Count of recordings (with parents)	9	Count of recordings (with parents)	12
Suggested questions	Frequency	Suggested questions	Frequency
Which model are you thinking of eliminating?	9	Tell me about the models.	13
How did you decide to eliminate that one?	4	Which model is better (or best) supported? (and why?)	12
Why didn't you eliminate this other model?	3	How would you revise it to make it even better?	2
Which models are you thinking you should keep?	6	What would you say to someone who thought another model was better?	10
Which model do you think is a better fit?	5	What evidence is most useful?	8
Why would you say this evidence supports both models?	2		

Parent Use of Other Questions

Parent talk other than the suggested questions were coded in six categories. Three of the categories related to the MEL, one was direction/procedure, one was clarification, and one was new ideas. Excluding the statements that were greetings or conversational like "ok," there were 66 statements in 12 of the 21 recordings. The number of statements by parents ranged from 0 to 21, with a mean was 4.33. The coding categories, the number of statements and the number of recordings that included these statements is shown in Table 14.

The parents who used other questions interjected the additional questions in between the suggested questions. Some skipped one question and indicated that the student had addressed the prompt in previous statements. Some referred to the model, evidence, or arrows and others asked for information about the assignment or the class discussion about the assignment, such as "how did you guys go over this in class?" The questions that were about models, evidence or arrows indicated that the parents were looking at some part of the MEL.

Table 14

Types of "Other" Parent Statements in Each Round

Code	Round 1		Round 2	
	Frequency	Count of recordings	Frequency	Count of recordings
Question: Models	1	1	15	5
Question: Evidence	3	2	2	2
Question: Coordinating	8	1	2	3
Direction/Procedure	4	2	3	2
Clarify	3	1	14	5
New idea	0	0	11	4

The same was true for the questions in the "clarify" category, where parents reworded the suggested question or restated a student answer. These questions often asked students to explain or interpret a part of the MEL. For example, one parent expanded on the suggested question by saying, "talk to me about the row with supports arrows for the two models. That means that the evidence could support both models?" One parent asked "Is that what the double arrow versus single arrow means?" Parents also repeated the student's words or rephrased their answer to ask a specific follow up question. One parent asked for a definition of a term the student used: "divergent." The parent asked the student to point to it on the MEL, and asked, "Where's it going? Opposite directions?"

In the "new idea" category, some questions exposed a gap in the student's explanation. Several parents asked students to address lines of evidence or models that they had skipped, e.g., by saying, "okay, how about model C?" One parent went further by noticing the student's response was missing at least one line of evidence. This parent said “Also, you could infer the heat flow part, right?” Statements in this category also introduced terms that the students did not yet use, such as “magma.” The terms that the parents introduced were often found on the MEL, so the student might have been familiar with it. I called it a “new” idea because the student had not yet talked about it in this discussion.

Parent Approaches in Both Rounds

This section compares the approaches in Round 1 to Round 2. I sorted the recordings into four categories: parents who followed the Round 1 suggested questions as if they were scripted, parents who followed the Round 2 suggested questions and parents in each round who used at least one original question. Table 15 shows the number of recordings in each category.

Table 15

Recordings by Type of Parent Questions in Each Round

	Round 1	Round 2
Only suggested questions	7	3
Other questions	2	9

There were differences between Round 1 and Round 2. I found of the 9 Round 1 recordings, parents in 7 of them used only the suggested questions, and 2 supplemented the questions with their own. In the 12 Round 2 responses, I found 9 parents supplemented the questions with their own while 3 kept to the suggested questions.

I examined the 11 recordings where adults asked extensive other questions that develop from parents rewording or repeating the questions or answers. This approach will be called active questioning. The parents who used the prompts in the order I suggested are described as taking a directed questioning approach. Figure 10 shows the portion of recordings in in each round that were active and directed.

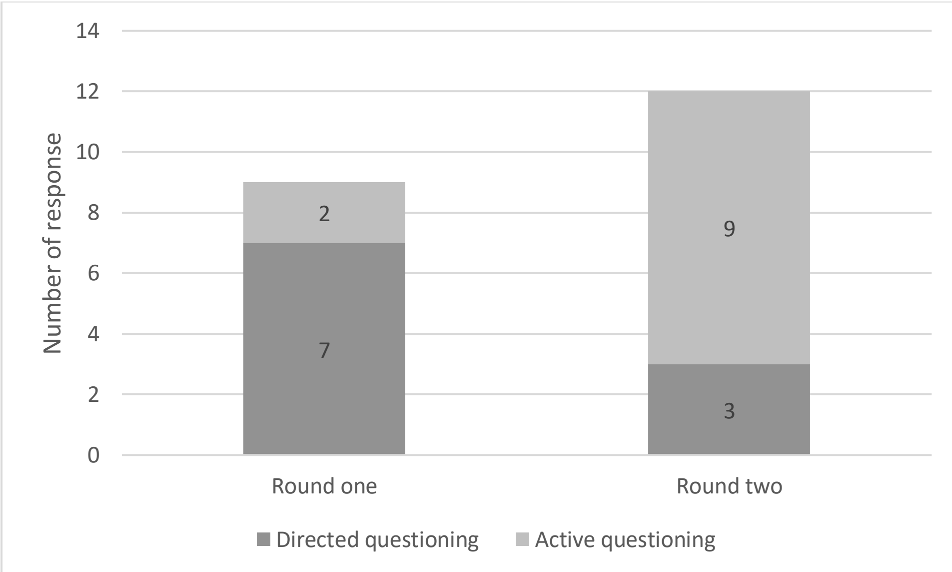


Figure 10. Parent Approach in Each Round

The suggested questions were used by all parents. Most parents, 9 of the 12, in Round 2 supplemented the prompts with their own statements and questions. The relationship between the guidance in Round 2 and the number of parents who used the active questioning approach will be discussed later in this chapter. In the next section, I describe the types of talk I saw from students to determine how the varied approaches of parents might help the student communicate their understanding.

Types of Student Talk

There were 21 recordings from individual students with parents. I coded all student statements independently and analyzed the number of statements overall. There were a total of 232 student statements within the 21 recordings. I excluded inaccurate talk and cues like “ok” which reduced the number of statements to 217. There were similarities and differences between Round 1 and Round 2 but no differences that met the criteria for statistical significance.

As shown in Table 16, students in Round 2 had more recordings and more statements overall. There were 12 recordings from Round 2 students and 146 statements, with a mean of

12.17 statements per student. Round 1 students accounted for nine recordings with 7.89 statements per student. A two-tailed T-test of the means results in a p-value of .06.

Table 16

Recordings From Students with Parents in Both Rounds

	Number of recordings	Number of student statements	Mean number of statements by each student
Round 1	9	71	7.89
Round 2	12	146	12.17

Types of Talk by Students in Each Group. Looking at the 21 recordings by individual students, I examined which types of talk were used in each recording. Model talk was found in 20 of the 21 recordings. Eighteen of the 21 students used evidence talk. A third type of talk, coordinating talk, was found in all 21 responses. Table 17 shows the number of recordings that include each type of talk.

I compared the types of talk in the recordings from Round 1 to Round 2. There were small differences. Students in Round 2 were more likely to use model talk and evidence talk compared to the Round 1 students. All 12 of the Round 2 students included model talk. Eight of the Round 1 students used model talk. Eighteen students included evidence talk, 7 of the 9 in Round 1 and 11 of the 12 in Round 2. All of the students in both rounds used coordinating talk.

Table 17

Talk by Student

	Round 1		Round 2	
	Number of recordings	Number of students who used this talk	Number of recordings	Number of students who used this talk
Model	9	8	12	12
Evidence	9	7	12	11
Coordinating	9	9	12	12

Amount and Distribution of Talk by Students in Each Group. I also examined the frequency of these types of talk in both rounds by counting the number of statements of each type. Table 18 show that students in Round 2 had more of each type of talk but there were no significant differences. In Round 2, students used between 1 and 16 statements of model talk, with a mean of 5.75 statements. There was one student in Round 1 who did not use model talk. The remaining eight used between 1 and 6 statements referring to models with a mean of 3.22. A two-tailed T-test results in a p-value of 0.10, leaving me unable to conclude there was a significant difference.

Table 18

Talk by Students in Both Rounds

	Round 1			Round 2		
	Number of recordings	Number of statements	Mean number of statements per response	Number of recordings	Number of statements	Mean number of statements per response
Model	8	29	3.22	12	69	5.75
Evidence	7	15	1.67	11	39	3.25
Coordinating	9	27	3.00	12	38	3.16

The number of evidence statements was higher in Round 2 than from Round 1. The number of evidence talk statements by each student ranged from 0 to 5 in Round 1 and 0 to 8 in Round 2. Compared to model talk, where the number of statements varied from one to sixteen, there was less variation in the number of evidence talk statements among students. Most students used evidence talk, 7 out of 9 in Round 1 and 11 out of 12 in Round 2, but they did not do a lot of it. The mean number of statements for students in Round 1 was 1.67 and in Round 2, 3.25. A two-tailed T-test resulted in a p-value of 0.06.

All students used coordinating talk. The range was 1 to 6 statements in Round 1 and 1 to 8 statements in Round 2. The mean number of statements by students in Round 1 was 3.00 and in Round 2 3.16. A two-tailed T-test results in a p-value of 0.84.

Distribution of Types of Talk by Each Group. I compared the different types of talk in Round 1 and Round 2. There were more statements in Round 2 overall. In both rounds, model talk was found most frequently. In Round 1, the types of statements were evenly distributed, with about 1/3 of the statements in each category. In Round 2, model talk represented a greater portion of the statements (49%) than in Round 1 (33%). The rest of the talk was evenly distributed between the other two categories. Table 19 shows the number of statements that make up each type of talk and the percent of the total talk that was in that category.

Table 19

Types of Talk Statements Both Rounds

	Round 1		Round 2		Both rounds	
Type of talk	Number of statements	Percentage of statements	Number of statements	Percentage of statements	Number of statements	Percentage of statements
Model	29	33%	69	49%	98	44%
Evidence	15	27%	39	29%	54	29%
Coordinating	27	30%	38	22%	65	17%
Totals	71	100%	146	100%	217	100%

I conducted a Chi-squared test and found a p value of .11. I concluded that there were no statistically significant differences in talk patterns from Round 1 to Round 2. The prevalence of model talk in Round 2 is possibly explained by the use of student-generated models, which had a variety of elements and may have required more interpretation.

Answers to Suggested Questions. I analyzed how the type of talk was related to the suggested questions. I present the count of how many students answered each question with each type of talk. This analysis helps to explain how the suggested questions helped facilitate talk about models and evidence. A student answer might include more than one statement, so a student can be counted in more than one type of talk. There was a straightforward relationship between some questions and model talk. If the parent asked a question “tell me about the model,” or “which model are you thinking of eliminating?” then the student often described the model. Evidence talk and coordinating talk was less directly related to any particular question. Table 20 shows the use of questions in Round 1 and the type of answer associated with each. Table 21 shows the questions in Round 2 and the associated answers.

Table 20

Types of Talk in Answers in Round 1

Suggested Question	Count of times used	Count of answer statements	Answers including Model talk	Answer including Evidence talk	Answer including Coordinating talk
Which model are you thinking of eliminating?	9	11	7	2	2
How did you decide to eliminate that one?	4	6	2	2	2
Why didn’t you eliminate this other model?	3	3	0	0	1
Which models are you thinking you should keep?	6	6	3	1	1
Which model do you think is a better fit?	5	9	2	2	4
Why would you say this evidence supports both models?	2	3	0	1	2
Totals		38	14	8	12

Questions Associated with Model Talk. Most of the model talk was associated with three questions: “Which model are you thinking of eliminating?” “Which model do you think is a better fit?" and "Tell me about the models." This is supported both by the number of statements and the number of students who responded to these questions with model talk. In each of the recordings when these questions were used, students answered with model talk. Of the fourteen

Table 21

Types of Talk in Answers in Round 2

Suggested Question	Count of times used	Count of answer statements	Answers including Model talk	Answers including Evidence talk	Answers including Coordinating talk
Tell me about the models.	13	21	12	4	4
Which model is better (or best) supported? (and why?)	12	21	4	5	10
How would you revise it to make it even better?	2	2	0	0	2
What would you say to someone who thought another model was better?	10	16	4	3	5
What evidence is most useful?	8	10	1	5	3
Totals		70	21	17	24

model talk statements in Round 1, seven were associated with these two questions. Of the 21 model talk answers in Round 2, twelve were associated with this question: "Tell me about the models." These questions elicited statements that often included contrasting or elaborating on the models. Students said "Model B" or "Model C" and described some part of the model. For example, one student said, "decided to eliminate model C since there's just water in the middle and model A has loose rock in the middle." Some students also explained the evidence against that model. One student elaborated for one minute twenty seconds, and the adult did not ask any further questions. Other students gave answers with explanations.

Questions Associated with Evidence Talk. Most students used evidence talk, but it made up less of the overall talk. With only 25 statements of evidence talk in both rounds divided among all eleven questions, there were no clear association between any question and evidence talk. The most productive question was the Round 2 question, “What evidence is most useful?” It was used eight times and five answers included evidence talk. Two other questions were associated with four or five evidence statements, but more frequently these were answered with coordinating talk.

Questions Associated with Coordinating Talk. The question most frequently associated with this type of talk was, “Which model is better (or best) supported? (and why?)” from Round 2. It was asked twelve times and ten students answered by applying evidence to the model. In the nine recordings where that question was not asked, all students made statements of this type in answer to other questions.

Answers to Other Parent Questions. Parent questions that were different than the suggested ones were coded as “other” questions and further categorized by type. The parents who used “other” questions often used more than one and sometimes more than one of the same type. Table 22 shows the number of times each question was used, the number of recordings where that type of question was used and the type of talk that was used in answering that question.

These results illustrate how different questions were associated with different types of talk. While one study of eighth grade students showed that more talk in peer groups was associated with higher reasoning (Hogan et al., 1999), we cannot assume that more talk is an indicator of more productive interaction or that one question is enough on its own to indicate a productive interaction. To determine whether these interactions were productive, I examined all of the statements from each student as a “response.” Each response was evaluated on a measure of quality. Then I compared the quality of the response in relation to the parent approach.

Table 22

Types of Parent Questions

Code	Number of times used	Count of recordings	Answer model talk	Answer evidence talk	Answer coordinating talk
Question: Models	16	6	5	3	4
Question: Evidence	5	4	0	2	2
Question: Coordinating	10	4	0	1	3
Direction/Procedure	7	4	0	0	0
Clarify	17	6	4	3	1
New idea	12	4	2	4	1

Quality of the Responses

I used Kelly and Takao’s (2002) argument quality scheme as a foundation to assess the quality of the responses. As described in Chapter 3, I coded all of the student statements by epistemic level, appropriate to grade six rather than undergraduate students, and applied to the specific topic of this assignment. I used the same number of levels (six) and names of the levels (I-VI) as Kelly and Takao and my descriptions of each level were similar. To assess the quality of the responses, I used three measures: the number of statements, the number of statements at the mid-level and the number of levels used in the entire response. In this analysis, the response is all of the statements recorded by the student. More statements in a response might indicate that the student has a more complete explanation, while more statements at the mid-level (Levels III, IV and V) might indicate that the student gave a scientific explanation, one that uses evidence to relate their observations to their ideas about geological process or to general scientific theory.

Similarly, the range of levels used in a response might indicate more connections between observations and theory.

I counted all of the statements in all the responses to see how they were distributed across the levels. Table 23 shows the number and percent of the statements at each level from students in each round. Statements at Level III, IV and/or V accounted for 148 of the 197 statements, or 75%. Statements at Level IV were most frequent, with 68 statements or 35%. This is attributable to the instructions to focus on linking data to models. In contrast, the undergraduates used Level I and Level V most frequently and used Level VI the least (Kelly & Takao, 2002). I also looked at how the statements appeared in Round 1 and Round 2. There were 45 statements from Round 1 and 152 statements from Round 2. Differences in the distribution were tested with a chi-squared test resulting in a p-value of 0.08. Statements at Level IV were most frequent in both rounds. Figure 11 shows the composition of statements at each level from each round.

Table 23

Distribution of Statements at Each Epistemic Level by Round

Level	Round 1 statements by level		Round 2 statements by level		Total	
	Number	Percent	Number	Percent	Number	Percent
I.	11	24%	14	9%	25	13%
II.	4	9%	11	7%	15	8%
III.	6	13%	51	33%	57	29%
IV	17	38%	51	33%	68	35%
V.	3	7%	20	13%	23	12%
VI.	4	9%	5	3%	9	5%
	45	100%	152	100%	197	100%

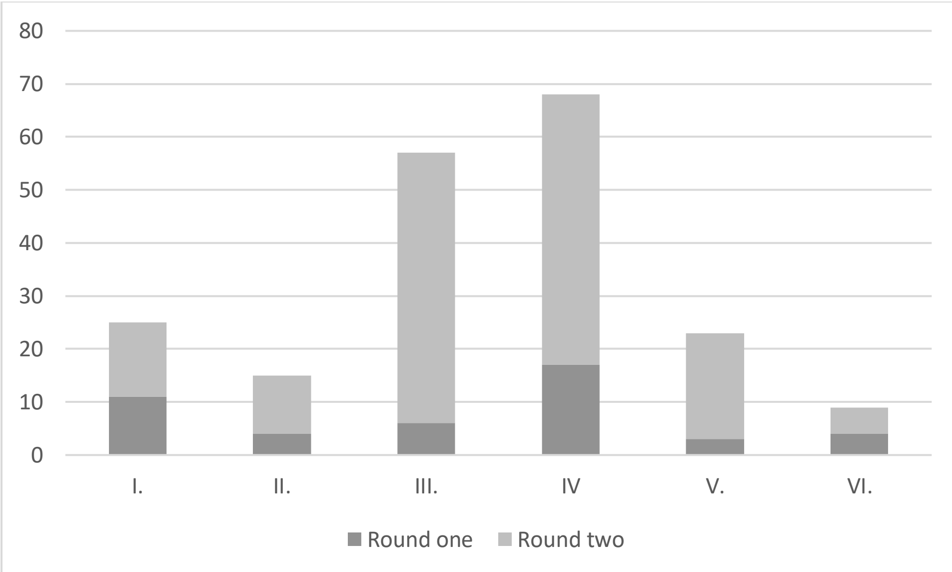


Figure 11. Number of statements at each epistemic level

To determine the quality of the responses by individuals, I counted the number of statements by each student. The number of statements in each response ranged from 0 to 22. I excluded from further analysis the response with no statements that could be considered epistemic. The mean number of statements was 9.75, the median was 7 and the mode was 6. Table 24 shows the characteristics of the responses.

Table 24

Quality of Response: Number of Statements

Number of responses	20
Total number of statements	197
Range of statements	2-22
Mean number of statements	9.85
Median number of statements	7
Mode number of statements	6

The number and distribution of levels used by an individual might show that the student is attempting to integrate observations and models as part of a scientific explanation. Students used a mean of 3.65 levels, with a range from 2 to 6. There were 10 students who used statements at 4, 5, or 6 levels and 10 students who used 2 or 3 levels. In addition, the most frequent level of the statements was Level IV. Nineteen of the students used Level IV statements. The single response that did not use Level IV used only Level I and II statements. In Table 25, I show these counts for all the responses.

Table 25

Quality of Response: Number of Levels and Mid-level Statements

Mean number of levels	3.65
Range of levels	2-6
Most Frequently used level	IV
Number of Level IV statements	68
Percent of Level IV statements	35%
Number of mid-level (III, IV, V) statements	148
Percent of statements at mid-level	75%

These counts give the impression that most students are using a variety of types of talk to explain their choice of models. The responses meet the criteria for a strong argument based on the work of Kelly and Takao, which expects strong arguments to use statements at a variety of epistemic levels. They found that in a high scoring paper, the propositions were distributed across the various epistemic levels, with many mid-level claims (epistemic levels II, III, and IV). In contrast, a majority of the propositions from the low scoring paper were classified into epistemic Levels V or VI. The low scoring paper was missing supporting evidence and had no propositions sorted into epistemic Level IV (Takao & Kelly, 2003, p. 356).

I was interested determining the quality of the responses from individual students in various groups. I compared these measures of quality: number of statements, the number of levels, the number of statements at levels III, IV, and V (mid-level) and the most frequently-used level.

Quality of Responses from Students in Different Groups. I compared the number of statements and the number of levels used by students from both Round 1 and Round 2, both types of parent approach (active and directed questioning) and girls and boys. I will describe the number of statements from each group, the mean number of statements and the mean number of levels for the responses from the students in each group. This analysis gives impressions about the relative quality of the responses from the students in those groups. These impressions were confirmed with further analysis of the number of statements at Levels III, IV, and V (mid-level) and the most frequent level from students in these groups. Table 26 shows the counts for the two rounds.

Table 26

Types of Statements in Round 1 and Round 2

	Round 1	Round 2	All
Number of responses	8	12	20
Total number of statements	45	152	197
Range of statements	2-7	2-22	2-22
Mean number of statements	5.6	12.7	9.85
Mean number of levels	3.1	4.1	3.65
Range of levels	2-5	2-6	2-6
Most Frequently used level	IV	III & IV	IV
Number of Level IV statements	17	51	68
Percent of all statements at level IV	38%	34%	35%
Mean number of Level IV statements per student	2.13	4.25	3.4
Number of mid-level (III, IV, V) statements	26	122	148
Mean number of mid-level (III, IV, V) statements	2.9	10.2	7.4
Percent of statements at mid-level	58%	80%	75%

There was a significant difference in the mean number of levels used by the students in Round 1 compared to Round 2. The mean number of levels in Round 1 was 3.1 and the Round 2 mean was 4.1. A two-tailed T-test shows a p-value of 0.05. There were more statements overall from Round 2 (152) than Round 1 (45). The mean number of statements was 5.6 in Round 1 and

12.7 in Round 2. For each of the 8 responses in Round 1, I counted the number of levels used by each student and found a range from 2 levels to 5 levels. In the 12 responses from Round 2, I found a range of 2 levels to 6 levels. Based on the number of statements and the number of levels, I found that there were more responses from Round 2 that represented strong arguments.

There was also a significant difference between the responses of students whose parents used an active questioning approach and those who used directed questioning approach. Table 27 shows the counts for these two groups. There were an equal number of responses in both groups. The number of statements from responses where parents used only the suggested statements was 76 and from responses where parents asked additional questions was 121. The mean number of statements was 12.1 for the active group and 7.6 for the directed group. The mean number of levels for the students whose parents used only the suggested questions was 3.1. For the parents who used more questions, the mean was 4.3. A two-tailed T-test shows a p-value of 0.01. Based on the number of statements and the number of levels, more responses from the active questioning groups represented strong arguments.

Table 27

Types of Statements by Parent Approach

	Active	Directed	All
Number of responses	10	10	20
Total number of statements	121	76	197
Range of statements	4-22	2-20	2-22
Mean number of statements	12.1	7.6	9.85
Mean number of levels	4.3	3.1	3.65
Range of levels	3-6	2-5	2-6
Most Frequently used level	III	IV	IV
Number of Level IV statements	39	29	68
Percent of all statements at level IV	32%	38%	35%
Mean number of Level IV statements per student	8.6	5.3	3.4
Number of mid-level (III, IV, V) statements	95	53	148
Mean number of mid-level (III, IV, V) statements	9.5	5.3	7.4
Percent of all statements at mid-level	79%	70%	75%

I also identified a difference between boys and girls responses. Table 28 shows the counts for these two groups. The boys used 156 statements and the girls used 41. The mean number of statements for boys was 12 and for girls it was 5.8. The range for girls was two to twelve. For boys, it was 4 to 22. The mean number of levels for girls was 2.9 and for boys it was 4.0. Based on the number of statements and the number of levels, more responses from the boys represented strong arguments.

Table 28

Type of Statements by Student Gender

	Boys	Girls	All
Number of responses	13	7	20
Total number of statements	156	41	197
Range of statements	4-22	2-14	0-22
Mean number of statements	12	5.8	9.85
Mean number of levels	4	2.9	3.65
Range of levels	3-6	2-4	2-6
Most Frequently used level	III	IV	IV
Number of Level IV statements	48	20	68
Mean number of Level IV statements per student	3.69	2.86	3.4
Percent of all statements at level IV	31%	49%	35%
Number of mid-level (III, IV, V) statements	121	27	148
Mean number of mid-level (III, IV, V) statements	9.31	3.86	7.4
Percent of all statements at mid-level	78%	66%	75%

Evaluating the Responses

The previous section describes the relative quality of the responses from the groups of students based on number of statements and number of levels used. These impressions were confirmed with further analysis of the number of statements at Levels III, IV, and V (mid-level) and the most frequent level from students in these groups. These criteria were based on the expected relationship between quality of the response and the epistemic levels of the statements that comprise the response. A response refers to the sum of all of the statements by the student that attempt to explain the models and the evidence presented. A higher quality response has more statements at a range of levels and includes statements at the middle levels. This definition is extrapolated from the argument analysis model developed by Kelly and Takao (2002), which identified the distribution of statements towards one end of the model and the absence of statements at the mid-level as markers of weaker arguments. It was necessary to identify the higher quality responses to characterize the parent-child interactions that were more productive.

To identify stronger arguments, I focused not just on the number of levels but the number of mid-level statements. The high-quality responses met the following criteria: at least six statements encompassing three or more levels and four of the statements at Levels III, IV, V. These responses involved instances where the student described the evidence, described the model, contradicted one model and supported another model. These students demonstrated the potency of evidence by using evidence to rule out one of the models or to justify the “best fit” model. In contrast, weak arguments used fewer statements (five or less) and fewer levels (two or less) and fewer mid-level statements (three or less). A weak argument was missing all of these characteristics, while stronger arguments could be lower on one characteristic but higher in another.

The argument analysis model predicts that the responses where students used fewer levels would be lower in quality. The inverse might also be true—the responses that use more levels are higher in quality. This is difficult to ascertain because the responses with more levels tended to have more statements overall: a mean of 11.6 for responses with four or more levels compared to 6.4 for the responses with two or three levels. The model works to identify weaknesses, but is not conclusive about strengths. In my analysis, I observed that weak arguments were similar to each other in that they used fewer statements, fewer levels and fewer mid-level statements, but stronger arguments were more diverse. High-quality responses might be stronger because they use more mid-level statements or more statements at a variety of levels. Below I describe the common characteristics of weaker responses and contrast them to stronger responses.

Responses With Few Levels. An example of a response that uses few levels is shown below. This is example is from Round 1 and has statements at two levels and four epistemic statements in total. There are several inaccurate statements, or the statements are ambiguous enough that I cannot determine that the student has a scientifically accurate understanding. These statements, which were not coded as an epistemic level, make me skeptical that the student's explanation as a whole is based on an understanding of the evidence. The parent statements are in parenthesis and the Level I-VI follows each student turn.

(Which model are you thinking of eliminating?)

I'm eliminating model C.

(How did you decide that to eliminate that one?)

I decided to eliminate model C since there's just water in the middle and model A has loose rock in the middle so it can cause many different things. Also, I don't think model C shows much evidence. (I)

(Which models are you thinking you should keep?)

I'm going to keep both models A and B. I think B has more supports arrows because the middle is new plate material. Also model A isn't completely accurate but it still gives a better explanation than model C. (I)

(Okay. What supports model A the best, model B the best and the model C the best?)

I think heat flow supports model A the best because the middle is loose rock. The heat from Earth's interior easily goes through the loose rock. I think the age of the sea floor supports model be the best because the rock in the middle is new from the two plates and I think GPS vectors is the only one that supports model C because it shows two plates pulling apart. (IV)

(What evidence strongly contradict the model C?)

A lot of evidence contradicts model C, but the piece of evidence that I think contradicts model C the strongest is that earthquakes, because earthquakes happen on land and not in water, and it just shows water in the middle while for the other two models earthquakes supports. (IV)

Similar to the example above, a response might be characterized as weak even if it includes some mid-level statements. The statements might be repetitive or disconnected from each other. For example, the response below from Round 1 used six epistemic statements at three levels including the mid-level, but the student uses the same rationale three times, worded slightly differently. The student says that Model C can be ruled out because there is no water inside the earth. The student does not draw on any of the evidence from the MEL but instead relies on a (grade-appropriate) textbook understanding of how magma forms.

(Which model are you thinking of eliminating)

I'm thinking of eliminating model C.

(Why would you eliminate model C?)

Because there is no water inside the earth's interior and there's only rock and magma inside the earth's Interior. The core melts the rock that turns into magma which rises from the Earth and the volcano and they go, yeah, there's evidence also there's evidence is strongly contradicts model C. Yeah. Okay. (VI)

(Which model are you thinking you should keep?)

Model A because okay. It's because it has loose rock material inside it and it, none of the evidence is strongly contradicts model A. (I)

(Why didn't you eliminate this model? What would you say to someone who thought this should be a contradicts arrow?)

They're wrong because there's something inside the earth. It's not just like nothing like the other one, model B or water inside it cause it's not liquid inside the Earth. Okay. No, and also none of the evidence… strongly contradicts for model A. (IV)

(Which model is the better fit?)

A because it has no strongly contradicting and it has stuff that it says that, it has stuff inside the inside the two plates. (I)

(What does it have inside the two plates?)

This rock material. Okay. Yeah. Okay. (VI)

(Which model do you think is better?)

Model A, Not model C because model C says water inside, there's no water inside. (IV)

Mid-level Statements in High-quality Responses. Based on the quality of responses that have few mid-level statements, I concluded that mid-level statements are an important criteria for a quality response. To determine the minimum quantity of mid-level statements necessary for a quality response, I compared the three responses with few levels (three) and few statements (less than six). Two of them used three statements at the mid-level and one used four statements at the mid-level. These were all from Round 1. They all had statements at Level I. The addition of more statements at Level I did not make any of these responses stronger. Instead, the one that had four statements at the mid-level was stronger. It used only five statements, four at Levels IV and V. Though it was less extensive than other responses with more statements, it was coherent and did not include inaccurate or repetitive statements. The response is transcribed below.

(Tell me about the models.)

Model A is loose or old Rock. Model B is solid rock and model C is water. They are all in models of the crust pulling apart from each other with these materials in the middle. (I)

(Which model is best supported and why?)

I think that B would be best supported because, because the evidence such as earthquakes, age of sea floor, volcanoes and GOS, all support that what B is saying. Earthquakes support model B because okay, because earthquakes are basically the movement of the plates and that is basically what Model B shows. The age of seafloor supports Model B because the inside hard rock is um, newer rock. (IV, V, IV)

(Which model are you going to eliminate?)

I 'm going to eliminate model C because, oh, okay. Some evidence are irrelevant or contradicts the evidence such as the age of sea floor, the heat flow and the GPS factors. Those are all irrelevant because they have nothing to do with the model and volcanos contradicts it because the model has the water in the middle, but in volcanoes the molten melted rocks are in the middle. Therefore, I think that model B is best supported and model C we should eliminate. (IV)

The analysis of responses suggests that the number of mid-level statements is related to the quality of response, but is not conclusive because the absence of mid-level statements is also related to a low number of statements overall. To strengthen the relationship, I examined the other two responses that used three levels, both from Round 2. Both had a larger number of epistemic statements overall (12 and 19) and all of the statements were at Levels III, IV, and V.

They were similar in that they were more coherent and accurate than the ones described above with fewer mid-level statements. In the example shown below, the student uses twelve statements. Some of the statements are repetitive, but even disregarding those, the explanation is more complete than the others with fewer mid-level statements.

> (What are the weaknesses for each model?)
>
> For example, in model A, the biggest weaknesses are that it does not show that the volcano is underwater and it also does not show that the volcano is higher than the surrounding sea floor. Also, it does not show why the plates and the earthquakes are causing the volcano to explode. Furthermore, in model B, the biggest weaknesses are that it does not show both lower valley and the volcano and it also does not show why the oceanic crust and the new rock pushing up is causing the volcano to erupt. Lastly, in model C, the biggest weaknesses are that it does not show the volcano underwater and it does all an also does not show the volcano being higher than the surrounding sea floor. Lastly, it does not show what is causing the volcano to erupt besides the water pushing up. (III, IV, V)
>
> (Which model would you rule out?)
>
> In my opinion, I would rule out model A. The reasons I would rule out model A are because the only evidence that shows is that the plates, the two plates and the two earthquakes are moving together and they are causing the volcano to erupt. It doesn't show why the volcano is erupting. It does not show any lower valley and it does not show the sea floor. (V)
>
> (Which model is the best supported?)

In my opinion, the best supported model would be model B. The reason for that is because it shows what is causing the earthquake to erupt. For example, it is showing that the oceanic crust is moving apart and the new rock pushing up is causing the earthquake to erupt. It is also showing that the volcano is underwater and that the volcano is higher than the surrounding sea floor. (III, IV, V)

(How would you revise it to make it even better?)

What I would do to revise model B to make it even better would be to show why the um, ocean crust and the new rock pushing up is causing the volcano to erupt. Also, I would show the lower valley and the volcano and I would explain how the volcano is higher than the surrounding sea floor. (III)

Criteria for High-quality Response. Because the number of statements and the number of levels are interrelated and because most students used some mid-level statements, to determine quality, I had to use all three criteria to define a high-quality response. In the 17 responses that included three or more levels, all included statements at both Levels III and IV or IV and V. These mid-level statements made up more than half of the statements in each response. Fourteen of these response used four or more statements at Level III, IV, or IV. These were labeled high-quality.

In looking at the other seven responses, I observed that they used six or fewer epistemic statements and three or fewer at Level III and IV. These students did not link the observational statements to the theoretical ones, but they did engage in a degree of critical thinking to evaluate the models. The assignment was elective, meaning that students could chose not to share their thinking, therefore all of the students who responded were at a minimum fulfilling the requirement of expressing their ideas, even if the quality of those ideas was low compared to others who completed the assignment. I call these “standard” responses.

To confirm the criteria set out above are valid indicators of quality, I share a response that is at the lower end of the criteria for high-quality response. It had a lower number of epistemic statements (six) with four of these statements at the mid-level. The response, shown below, used statements at four levels, between I and IV. I only included the epistemic statements by the student.

> So there are three models and we're trying to see which model represents a well I an accurate volcanoes best. So we took four factors. So an accurate volcano and we're seeing which model represents the four factors the best. (I)
>
> Cause the volcano is higher in the surrounding floor, but there is not a lower valley in the middle. So I only think it supports it a little bit for not like strongly support. (III)
>
> Yes. Um, also, um, with the age of the sea floor, there's younger rock, um, uh, here you can see those younger rock a center and there's older rock on the sides, like pushing out. (II)
>
> And I think that strongly supports because you can see it pushing out with the arrows. (I)
>
> so for the heat flow, the highest, the highest t is along that the divergent plate boundaries. As you can see here, it shows that the highest heat is along the divergent plate boundaries, (IV)
>
> And it shows plate and with the GPS vectors it shows please diverging. Um, I, I, I put this support because on the, on the evidence paper it says that it's supposed to be about 2.5 centimeters per year, but you can't really tell how, how far going. So I only put it support because it only supports it a little bit, like not, (IV)

> I thought that for it was, it was model B age of sea floor and heat flow because those ones really supported and they really like helped understand, helped explain like they helped show, which is it helped show when accurate volcano actually looked like with the heat flow in the age of sea floor. (III)

This example shows that even without a lot of epistemic statements and without a lot of textbook vocabulary definitions, the student was able to describe the models, present the evidence and connect it to their understanding of the models. This example is also significant because it includes a lot of parent talk, outside of the suggested questions. This parents used an active questioning approach. I address the question of how the parent approach is related to the quality of the response below.

Quality of Responses and Parent Approach

With these criteria for response quality, the quality of the response was not significantly related to the parent approach. I observed some differences that point to questions that might be answered with a larger sample. There were fourteen responses labeled as high-quality and seven were standard. There were eleven responses where parents engaged in active questioning and ten where parents used directed questioning. Nine of the twenty-one responses were both high-quality and active questioning and all were from Round 2.

Quality of Responses With Directed Questioning. Direct questioning was just as likely to be associated with a high-quality response as a standard-quality response. Table 29 shows how the responses were associated with the parent approach. There were five high-quality responses with parents who used the directed questioning approach. One of the first responses was a high-quality response from a student who completed the assignment on the first day it was open. This student offered a thorough response with little prompting; the parent asked only two questions.

There were also two responses from Round 2 where parents used directed questioning and the students gave high-quality responses. There were an equal number of responses—five—that were standard-quality where parents used a directed questioning approach.

Table 29

Quality of Responses by Parent Approach

Parent approach	All responses	Standard-quality responses		High-quality responses	
	Count	Count	Percent	Count	Percent
Directed	10	5	50%	5	50%
Active	11	2	18%	9	82%

Quality of Responses With Active Questioning. The active questioning approach was not associated with high-quality responses. Nine of the fourteen high-quality responses were found with parents using the active questioning approach. Not all of the active questioning prompted students to expand on their answers. There were two cases where parents used active questioning but the responses were not high-quality. A Chi-square test was performed to determine the probability that high-quality responses were associated with active questioning. The result was insufficient to reject the null hypothesis.

A larger sample size might confirm the impression from the data that the active questioning approach is associated with higher quality responses. The percentage of active questioning responses that were high-quality is 82%, and 50% of the directed questioning were high-quality. This finding, in combination with the finding that there was a significant difference in the amount of talk and in the number of levels suggests that active questioning by a parent is related to a stronger argument by the student.

Quality of Responses in Each Round

There were fourteen high-quality responses and 11 were from Round 2, as shown in

Table 30. To determine whether the high-quality responses were related to Round 2 I performed a Chi-square test. This yielded a $\chi 2$ value of 4.57, significant at .05. In Round 2, 92% of the responses were high-quality, while in Round 1 33% were high-quality. Because Round 2 had more active questioning, there is a possibility that the combination of Round 2 questions and the active questioning approach were responsible for the higher quality responses. Nine of the 14 high-quality responses were from Round 2 with parents using the active approach. I explore how this result might be related to differences in the guidance from Round 1 to Round 2 in the next section.

Table 30

Quality of Responses in Each Round

Round	All responses	Standard-quality responses		High-quality responses	
	Count	Count	Percent	Count	Percent
Round 1	9	6	67%	3	33%
Round 2	12	1	8%	11	92%

Parent and Student Interactions in High-quality Responses

I examined the parent-child interactions in high-quality responses, where students described the evidence, described the model, contradicted one model and supported another model. In some of these interactions, parents took an active approach, rewording the suggested questions, adding clarifications, restating student answers, or adding new ideas. In many of these interactions, students responded to parent-initiated questions with further explanation.

One parent expanded on the suggested question by saying, “talk to me about the row with supports arrows for the two models. That means that the evidence could support both models?” The student responded by explaining that all three models were supported with GPS evidence. She went on to describe why she used double arrows to show that the GPS evidence “strongly supports" one of the models. Here, the parent's question, rephrased from the suggested question, prompted the student to make a distinction between the models, a distinction no other student made. The student said that while the GPS evidence supported all three models "because those are the arrows showing that the plates diverge," but she used a double arrow for one model to show that evidence strongly supports one model more than the others.

Parents also repeated the student's words or rephrased their answer to ask a specific follow up question. One parent asked for a definition of a term the student used: "divergent." The parent asked the student to point to it, and asked, "Where's it going? Opposite directions?" The student responded by agreeing and further explaining that the GPS evidence "strongly supports plates diverging."

Another type of interaction occurred when a parent pointed out a gap in the student's explanation. Several parents asked students to address a model that they had skipped, e.g., by saying, "okay, how about model C?" which prompted the student to explain that model. Another parent went further by noticing the student's response was missing at least one line of evidence. This parent said "Also, you could infer the heat flow part, right?" The specificity of the parent's follow up question prompted the student to recognize the missing part and respond. The student continued by using the lack of evidence for heat flow to eliminate one of the models, making the question effective.

Other parents added new ideas, sometime coaching their students, attempting to guide or correct children's thinking. An indication that the parent was coaching was the use of terms that were not used in class such as "factors" to mean evidence statements. Another indication is when parents attempted to direct or redirect the student. The parent might say "but not to the extent of" to steer the student towards another model. These cases might be seen to demonstrate the "right answer” orientation that other researchers have observed in parents. In those scenarios, parents direct the students towards the perceived correct choice. The right answer orientation was apparent if the parent comment was followed by a student making a conclusion about the model, ending the discussion. However, students often did not respond. When they did respond, it was with a defense or a counter-claim rather than a conclusion.

Another type of interaction involved the parent offering encouragement. Encouragement differed from questioning or coaching. Some encouragement was in the form of a parent making a connection that the parent thinks is relevant. Some parents referred to language, asking the student if they knew the Spanish word for volcano is “el volcán,” or to a shared memory, “in Greece there is a volcano by Santorini.” Sometimes the encouragement was rephrasing the student’s comment with approval or agreement: “I guess you have a nice way of justifying why you wouldn't have picked that one. It's a good job on that.” Like coaching, encouragement was not successful at exposing student understanding, but it may have had a positive influence.

I observed responses where active questioning did not produce student statements. One parent repeatedly tried different prompts: “So can you draw some of the pictures?” and “Can you give me some examples of maybe a country or state?” The student said “no” and gave reasons why the parent’s suggestion was unnecessary or extraneous. Another parent said, “Is that what the double arrow versus single arrow means?” This student did not audibly respond and continued describing the evidence.

Overall, student responses to the parent activities were positive if not successful. The student focus group confirms this impression. The student comments from those who participated with their parents were generally neutral or positive. Students may have been reluctant to share their feelings about the experience in front of their peers who may or may not have had a parent partner. This was especially apparent prior to the assignment, when both publicly and confidentially students expressed reluctance to request parent assistance. Outwardly, students were confident they could do the assignment on their own. In contrast, after the assignment, the students who did not participate with parents said it was because of parent's lack of time.

Summary of Findings

In this chapter, I described the findings from the analysis of the recordings. I coded the adult talk to develop two categories for the parent approach: directed questioning and active questioning. Parents who used a lot of "other" questions, different from the suggested questions, were taking the active questioning approach. These questions were formulated from parts of the MEL. There were ten responses in which parents took a directed questioning approach and eleven responses where they used active questioning.

Student talk turns were coded into basic categories with quality weighting. I analyzed the amounts and types of student talk in both rounds. The recordings in Round 2 were longer, there was more talk and there was more of each type: model, evidence, and coordinating talk. This may be related to the models being student-generated rather than standard diagrams.

I used an argument analysis model (Kelly & Takao, 2002) to assess the quality of the responses. In the process, I noticed that an important element of a high-quality response was a number of statements that link the observations to the theory or evidence to the models. These statements were numerous and nineteen of the twenty-one students used them. This is attributable to the instructions to focus on linking data to models. There was a significant difference in the mean number of epistemic levels used by the students in Round 1 compared to Round 2. Students in Round 2 used more levels. A third element was the number of statements used in a response, and again, there were more statements in Round 2 than Round 1 and students in Round 2 used more on average than students in Round 1.

I defined high-quality responses as those that had at least six statements encompassing at least three levels and included at least four statements at the middle levels. I used this definition to find relationships between high-quality responses and the guidance from each round and high-quality response and the parent approach. I found that there were 11 high-quality responses from Round 2 and only 3 from Round 1 and that high-quality responses were significantly related to Round 2. Round 2 had different guidance than Round 1—both the suggested questions and the source of the models at the top of the MEL were different.

I also looked for interconnections between parent approach and high-quality student responses. I identified eleven responses in both rounds where adults took an active questioning approach and in nine of these (82%) students gave high-quality responses. Fifty percent of the responses that used directed questioning were high-quality. This finding, in combination with the finding that there was a significant difference in the amount of talk and in the mean number of levels suggests that active questioning by a parent is related to a response of high quality.

The results indicate that differences in the use of guidance were associated with different patterns of parent-child interactions. Two relevant features were the suggested questions and the source of the models that were discussed. These differences in these features, mediated by the active questioning approach, may be responsible for the high-quality responses.

CHAPTER FIVE: DISCUSSION

The purpose of this design-based intervention study was to understand and support parent-child interactions in the context of scientific inquiry. From previous studies, we know that family participation in school-related activities, especially those that foster academic attitudes, ideas, and behaviors and perceptions of competence, can positively influence student outcomes, whereas other forms of help can be detrimental to students (Hill & Tyson, 2009; Hoover-Dempsey & Sandler, 1995, Steinberg et al., 1992). Science discourse is a skill that is ready for student improvement through practice with parents. Despite a variety of interventions, lack of participation in discussion is a persistent obstacle to learner engagement (Clarke, 2015; Mercer, 1996; Mercer et al., 1999; Webb, 1989).

The goal of the intervention was to facilitate scientific discourse in parent-child interactions. The conjecture map presented in Chapter 1 (reproduced below, Figure 12) was used throughout the study as a hypothesis about the design of the intervention and how participants would interact with the features—to specify those features and to explain mediating processes (Sandoval, 2004, 2014). As a design experiment, this study was iterative and interventionist, and it addressed the interactions between the features. As I observed and analyzed the interactions between participants and the tools and materials, I refined the conjecture map to reflect the critical characteristics of the design features. In this chapter, I refer to the conjecture map to summarize the results and determine how the goal of the intervention was achieved.

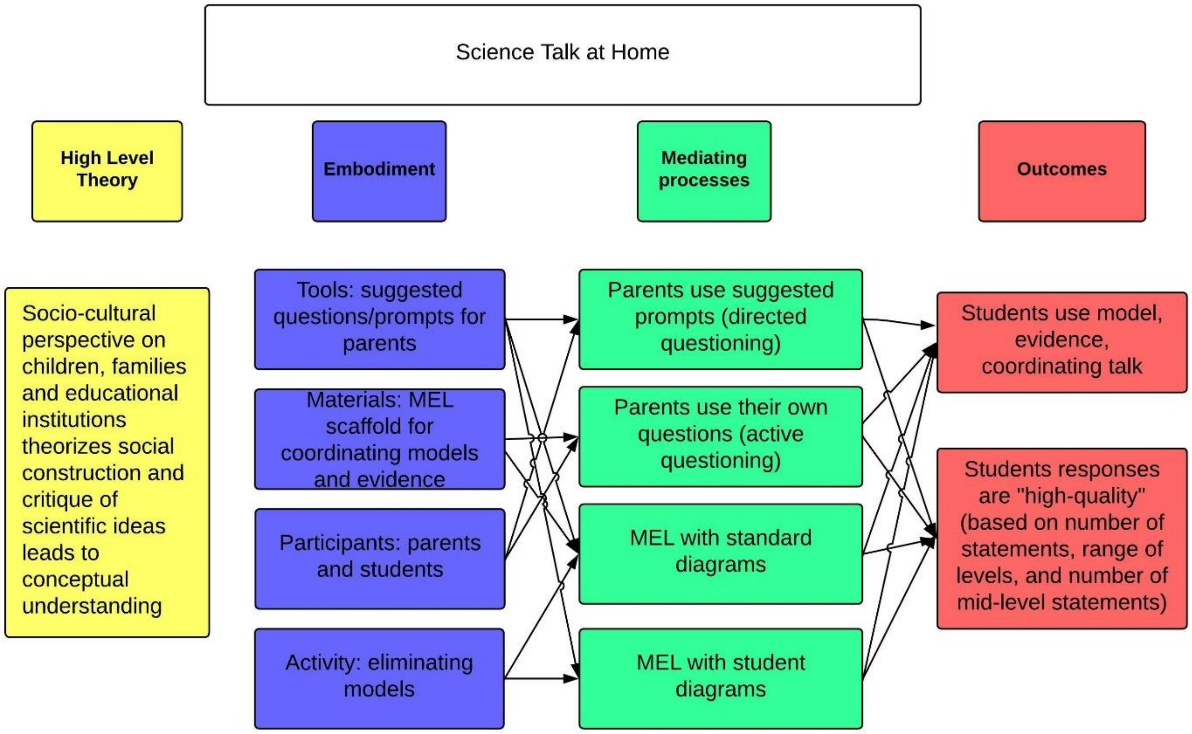


Figure 12. Embodied Conjecture

The embodiment of the conjecture included tools, materials, participants and activity structures. In brief, sixth grade science students and their parents were asked to cooperatively compare models explaining the formation of an undersea volcano to eliminate one of them in light of the accumulated evidence. The parents were given suggested questions, and students were given a Model-Evidence-Link (MEL) scaffold that was created through classwork.

The structure of the conjecture map helped me think about the reporting the findings as a two-stage process. First, I needed to describe how the design features were used, and second I needed to connect their use to the learning outcomes. The two design features that were critical were the MEL and the suggested questions. My analysis showed how the MEL with student-generated diagrams was used differently than the one with standard-diagrams. I also showed that many parents also elaborated on the suggested prompts, initiating their own questions. These two observations were added to the embodied conjecture as mediating processes. I tested ideas about how the mediating processes were related to the type and quality of talk used by the participants. These general outcomes became more specific as the analysis was completed: The types of talk were model, evidence, and coordinating talk, and the quality of a response was determined by the statements that integrated theory with observations.

These outcomes were mediated by the parent approaches and aspects of the MEL. The use of the MEL was responsible for most students making connections between the evidence and one or more of the models. Some interactions showed that parent-initiated questions outside of the suggested questions and materials helped students describe and coordinate the models and evidence. The "active questioning" approach resulted in more students giving a high-quality response that explained why a model is either a good fit or one that should be ruled out. In sum, providing parents with suggested questions and students with the MEL helped students engage in scientific discourse and give scientific explanations.

Beyond explaining how the intervention worked in this specific context, a design experiment should also contribute a theoretical understanding of the learning process (Cobb et al., 2003). Thus in this chapter, with the conjecture map as an organizing framework, I summarize and interpret the findings of the two research questions: (a) What are the features of the guidance (instruction, training, and scaffolds) that facilitate parent-child interactions? (b) What talk moves by parents and children are associated with more productive discourse? I discuss the literature on scientific discourse among school-aged children and models of family engagement. I add my reflections on this experience and propose how future research might build on these findings and offer suggestions for effective family engagement programs. Finally, I outline the limitations of this study and present a conclusion.

Findings for Research Question 1: The suggested prompts for parents and the Model-Evidence-Links Matrix (MEL) were critical features of the intervention

Research Question 1 asked: What are the features of the guidance (instruction, training, and scaffolds) that facilitate parent-child interactions? The amount of science talk was used as an outcome measure for parent-child interactions. The results show that the suggested questions were used by all parents and were associated with students talking about the models and evidence on the MEL. Parents used the questions in different ways, but they all used at least some of the questions in the suggested order. The students responded to the suggested questions with talk about models and evidence. All students engaged in this discourse in some way, though some students made extensive statements and some students made limited statements. Even with these individual variations, model talk was found in 20 of the 21 recordings, evidence talk in 18 and coordinating talk was found in all 21 responses.

.The use of the MEL was a critical feature that enabled the additional expression of ideas by serving as a common reference between the students and the adult partners. I found that students who did not refer to the MEL had only limited talk about models and evidence. In contrast, students who did use the MEL expressed justifications for arrows and communicated why an arrow was a support arrow or why an arrow was a contradicts arrow. The arrows are a unique feature of the MEL that distinguishes it from many other science worksheets. The development of the MEL was described by its designers in Rinehart, et al. (2014). I will describe here how, in combination with the suggested “why” questions, the MEL enabled students to explain why a model is either good fit or should be ruled out.

I used the MEL in class to keep track of evidence and I directed students to compare each line of evidence for or against each of the models. The students collaboratively evaluated whether each evidence statement supported or contradicted each of the three models. The completed matrix supported the final task, to select one explanatory model from among several alternatives, a cognitively challenging activity. Students used the MEL to compare the models, to define the criteria they would use to make a choice, and to evaluate each model based on that criteria. These explanatory statements giving reasons for preferring one model over another were coded as “coordinating” talk. All students used this type of talk, for a total of 65 statements, or 30% of the total talk. Students used on average 3.1 statements.

Students used coordinating statements to report which arrows were used or make a claim about a model’s fitness. An example is: “Models C and A, there, some are relevant arrows and some contradicting and strongly contradicting arrows.” Other statements referred to one model without giving reasons: “in my opinion, the best supported model would be model B.” These statements, while not substantial justifications, represent student efforts to compare models and define the basis for comparison.

Other students pointed out how the evidence statements applied to two or more of the models. For example, one student compared all three models to the GPS evidence and noted that only one model had a supporting arrow. Students also counted the number of each type of arrow that each model had. One student declared one model best supported because it had more supports arrows. Another declared it was best because it had no contradicts arrows. “Model C is better supported than Model A because it has more supporting arrows and less contradicting arrows.” The words “more” and “less” show that the student has compared the types of arrows used in Model C to the arrows for Model A. Another type of comparison is when students compared “supports” to “strongly supports” arrows. An example of this type of statement is:

"Model C is better supported and I believe it's better supported because it has a very strongly supported topographic evidence."

Students also used the arrows to weigh more than one line of evidence, sometimes referring to the body of evidence for one model compared to the body of evidence for another model. An example is: "Model C is better supported … because it has a very strongly supported topography evidence and evidence that it shows age of seafloor…because it has very supported heat flow evidence and it has some very super strongly supported GPS vectors." Other statements referred to the evidence represented by the arrow, for example: "the piece of evidence that I think contradicts Model C the strongest is that earthquakes, because earthquakes happen on land and not in water, and it just shows water in the middle…" In this example, the word "strongest" means that the student compared the earthquake evidence to the other lines of evidence and gave that more weight in ruling out Model C.

The evaluations and justifications represented by coordinating talk were possible because of the arrows on the MEL matrix. These arrows helped student to compare the overall strength of the supporting lines of evidence. When two models had the same number of supports arrows, the MEL helped student articulate the reasons why they "counted" some evidence statements more than other. The arrows also helped students identify contradicting lines and used the contracts arrows to "rule" out one model, thus making explicit the power of a contradicting evidence statement. In sum, the student used the MEL to express their thinking about why one model was a better fit than another by describing the criteria for their evaluation.

Differences in the suggested questions and the MEL between Round 1 and Round 2 allowed a comparison of the resulting talk, providing further evidence of the importance of these features. There were more statements in Round 2 overall, and model talk represented a greater portion of the statements in Round 2 (49%) than in Round 1 (33%). No statistically significant differences occurred in talk patterns from Round 1 to Round 2, ruling out that the differences in the suggested questions had a significant effect on the type of talk in the responses. Instead, the effect on responses may have been mediated by type of parent approach and by differences in the MEL.

Parent approach was characterized as one of two types: Some parents used only the questions in the suggested order while other used the suggested questions and their own additional questions. These two approaches were labeled “directed questioning” and “active questioning,” respectively. Two parents in Round 1 and 9 of the 12 in Round 2 took the active questioning approach. The supplemental questions were developed from the models and evidence on the MEL. The parents in Round 2 who used the active approach also formulated more questions based on the MEL than those in Round 1.

The tendency of parents in Round 2 to take the active questioning approach is attributable to differences in the MEL. The instructions to parents and students in both rounds were the same. In Round 2, the MEL had models that were student-generated and had greater variety of elements while in Round 1 the diagrams were standard line-drawings with only one obvious difference between the three.

As a result of these two mediating processes, students in Round 2 were found to have more explanatory talk describing, evaluating, and coordinating models and evidence. The learning implications of this outcome are discussed below.

Findings for Research Question 2: The active questioning approach was associated with high-quality responses

Research Question 2 asked: What talk moves by parents and children are associated with more productive discourse? To characterize the type of talk moves associated with productive discourse, I developed a measure of response quality based on Kelly and Takao's (2002) argument quality scheme. I used three indicators: the number of statements, the number of statements at the mid-level and the number of levels used in the entire response. More statements at the mid-level (Levels III, IV and V) and a higher range of levels used in a response indicate more connections between observations and theory. These statements were a component of high-quality responses.

The students who had a parent use an active questioning approach had more statements overall, more statements at the mid-level, and a higher mean number of levels. The percentage of active questioning responses that were high-quality was 82%, while 50% of the directed questioning responses were high-quality. Likewise, students in Round 2 used more statements, more statements at the mid-level, and there was a significant difference in the mean number of levels. The percentage of Round 2 responses that were high-quality was 92%, while 33% of the Round 1 responses were high-quality. High-quality responses were significantly related to Round 2. Nine of the 14 high-quality responses were from Round 2 with parents using the active approach.

Productive discourse, demonstrated by high-quality responses, was common in responses from Round 2 where parents used the active questioning approach. These responses were often marked by parents' encouragement, while other parents engaged in discursive action that might be called coaching. Studies of classroom discourse between teachers and students offer some insight into how these discourse acts might help students talk more and how more explanatory talk might benefit students reasoning.

Interpretation of Findings: Parent Talk Moves

Parent talk moves were associated with student statements that integrate observations with scientific theory. These exchanges represented a form of scientific discourse. Much of what we know about scientific discourse comes from studies of teachers and students in the classroom. In this section I give examples of the exchanges to illustrate how they are similar to teacher talk moves and to understand how they might help students learn by talking more or reasoning better. I contrast these to a common classroom exchange known as IRE (Initiation, Response, Evaluation).

Some of these talk moves are direct, explicit instructions to students and others are indirect and are open to interpretation by students. "Revoicing" is an example of an indirect talk move used by parents in the active questioning approach. Described by O'Connor and Michaels (1993) "revoicing" is when a classroom teacher reformulates student ideas into more standard forms during discussion. It "lends power and authority to the student's relatively weak voice, while at the same time it allows the student to retain some ownership over the reformulation." I observed parents restating student ideas using the terms from the MEL: "then that means the heat surface flow for all of them. That's why we say it's irrelevant." Other parents revoiced student ideas using general terms "…then the age of the sea floor model A doesn't help you at all." Moreover, when the student agreed with the revoicing, the student got credit for the more powerful or sophisticated form (O'Connor & Michaels, 1993). In these turns, the student received an evaluation of their idea but unlike in the IRE mode, the student rather than the adult had the chance to compare what was said to what they expected.

Direct parent talk moves were similar to the teacher acts classified by Wei et al. (2018) as challenging and prompting. Some of the suggested questions were challenges and prompts but parents also created their own. I will give examples of both the suggested questions and the parent-initiated ones and explain how students might respond. Challenging is a move that encouraged students to provide a justification for their responses or to consider alternative points of views. Some of the suggested questions that I provided were challenges ("Why didn't you eliminate this other model?" or "What would you say to someone who thought…") but parents also came up with their own challenges ("Is that what the double Arrow versus single Arrow means?" "Do you still think that?"). These questions had students check their errors and assumptions. Other challenges suggested a new or alternative argument ("Model C didn't think helped either. Right?"). Wei et al., said that the goal of a challenge is to probe students' critical and analytic thinking as they consider and compare multiple perspectives after sifting through reasons and evidence. In one study, children's responses indicated that challenging was a successful scaffolding move (Jadallah, 2011).

Another type of talk move that might promote in-depth thinking and high-level comprehension is called prompting (Wei et al., 2018). These are open-ended questions that ask for students' thoughts, justifications or interpretations (Chinn et al., 2001). The first suggested question in Round 2, "tell me about the models" was an example of a talk move that fits into this category. In another example, a parent invented their own prompt: "talk to me about the row with supports arrows for the two models. That means that the evidence could support both models?" Other prompts asked for evidence ("What evidence strongly contradict the model C?") (Jadallah et al., 2011). The goal was to encourage students to generate more thoughtful and elaborated responses. As opposed to the IRE mode which ends with an assessment of correctness, a prompt helped the participants collaboratively construct meaning (Wei et al., 2018).

Encouraging parents to engage in questioning using prompts and challenges rather than an IRE mode of questioning might have had an effect similar to that of a teacher in classroom discussion. Jadallah et al. (2011) found that prompts, challenges and clarifications were likely to be followed by children's use of evidence and children's use of evidence was likely to be followed by praise for the use of evidence. Jadallah et al. also noted that students began to ask each other to locate evidence, labelling this as "appropriation." Parent-child interactions at home that included revoicing, challenges and prompts might have a similar effect on the student's later participation in classroom discussion.

Interpretations of Findings: High-quality Responses and Learning

The cognitive benefits of participation in scientific discourse has been seen in classroom studies where students engage in dialog either with peers or a teacher (Hogan, et al., 1999). I will summarize the findings from Hogan et al. (1999) in order to explain how they relate to the findings in this study. The study observed groups of students in eighth-grade science classes discuss mental models of the nature of matter, tracked the type of talk in the groups both with the teacher present and without and assessed the level of reasoning and quality of explanations they produced. Because of the similarities between the parent-child discussions and the eighth-grade classroom discussion, I contend that the high-quality responses comprise complex reasoning.

In parent-child discussions, the high-quality responses associated with the active questioning approach seem to correspond to Hogan et al.'s elaborative pattern, which was the most productive pattern of interaction in both peer and teacher-guided groups. In elaborative sequences all speakers contributed multiple substantive statements that built on or clarified another's prior statement. In contrast, the standard responses (mostly associated with the directed questioning approach) are similar to their consensual pattern. In consensual sequences one speaker carried the conversation, with one or more speakers serving as a minimally verbally active audience. One speaker contributed substantive statements, and the other speaker responded to the initiating speaker by simply agreeing with the statement or passively or neutrally acknowledging the statement, or by actively accepting what was said and thereby encouraging the speaker to continue, or repeating the preceding statement verbatim. Hogan et al. showed that when participants in a discussion built on one another's contributions, the sophistication of reasoning increased. Based on the similarities between the elaborative sequences and the high quality responses with an active questioning approach, I expect these responses would also show higher reasoning complexity.

The discussions I observed, however, were more like peer-group discussions than teacher-led groups. Parents were not directed to lead the students to a particular answer but were able to ask questions that generated and explored ideas. As Hogan et al. noted about peer groups, "students were participating on the border between what they knew and did not know, without the benefit of a more scientifically knowledgeable participant who could guide and clarify contributions to the knowledge construction process." Teacher-led groups had discussions that achieved higher-level reasoning, but in the absence of a teacher, peer groups could reach similar high levels of reasoning by engaging in more turn-taking exchanges. This suggests that it might take more talk for some parent-child pairs to reach higher reasoning than it would with a teacher.

The role of the parent in this study is important from a socio-cultural, constructivist perspective. This study began with the idea that students explaining to themselves would help them identify weaknesses or gaps in their explanations. This initial idea was based in Chi's work on self-explanations. But others have posited that the development of reasoning through talk depends on argumentation with an external other. I thought that adding parents to the intervention would address both the parents desire to be informed of their children's school work and their prompting would aid in the students explanations. Two socio-cultural constructivist concepts might help us interpret how prompts might help students' cognitive development: "role" and "appropriation." When parents took the active questioning approach, they took on the role of student rather than the teacher, as in the peer groups studied by Hogan et al. (1999). Examining the longest response in the first round, I found that the parent-generated prompts allowed the children to explain as if they were the teacher. In the standard responses, the parents took an interrogatory or IRE approach by asking only the suggested questions. Second, revoicing and making students the authorities – the ones with the answers – is a means of "appropriation." Rogoff (1995) defines appropriation as a ‘‘process by which individuals transform their understanding of and responsibility for activities through their own participation’’ (p. 150). The "role" of the parent in active questioning approaches and "appropriation" by students in high-quality responses might explain some of cognitive benefits others have seen from students gaining from giving elaborated explanations. Positive learning outcomes have been associated with discussions in which students express complete scientific explanations of models and evidence (Berland & Reiser, 2011, Osborne et al., 2016; Resnick et al., 2015).

Interpretation of Finding: Family Engagement in At-home Learning

This study was designed to understand the characteristics of productive parent-child interactions. In this section I discuss this findings in light of two prominent models of family engagement, Hoover-Dempsey and Sandler model and the Epstein model. The Hoover-Dempsey and Sandler model, as discussed in Whitaker (2019), outlines how parents' involvement efforts may contribute to the development of key academic beliefs and behaviors. The Epstein model, as summarized in Epstein (1995), offers theory, framework, and guidelines that should help schools take steps towards building partnerships. This study provides evidence for both models in three categories: (a) the actions of parents, (b) the perception of students, and (c) a portrayal of an effective family engagement program.

The analysis provides insight into the parent enactment of “learning at home” from the Hoover-Dempsey and Sandler (2005) model. The learning mechanisms that parents engage in when they are actively involved in their students learning into four categories: Encouragement, Modeling, Reinforcement, Instruction. The parents in this study who used an active approach engaged in talk that fell into these two categories: encouragement and reinforcement. Hoover-Dempsey and Sandler’s (2005) definition of encouragement, the explicit affective support for their child’s engagement in school. These learning-related activities are evident in the active parent approach that I call encouragement. The approach that I call coaching falls into the category of reinforcement. The traditional forms of involvement, such as quizzing and homework help, enable students to rehearse and affirm their knowledge.

This study also contributes to our understanding of how students perceive this experience, Level Four in the Hoover-Dempsey and Sandler (2005) model. As the main actors in their education, development, and success in school, students are at the center of a school-family partnership, and activities may be designed to engage, guide, energize, and motivate students to produce their own successes. The students’ responses to this experience reflect their ambivalence to parent assistance. Prior to the assignment in class, both publicly and confidentially, students were confident they could do the activity on their own. Students expressed reluctance in requesting parent assistance. After the assignment, those students who completed it independently suggested it was because their parents were too busy. Students’ attitudes about their independence from their parents represent the transitional stage of late childhood or pre-adolescence.

Student perceptions of the experience can also be inferred from participation rates. After noticing the smaller-than-expected number of students participating with their parents in Round 1, I made additional efforts in Round 2 to suggest to students that an adult partner could be helpful. In Round 2, more students participated with an adult, but there were fewer overall students who completed the assignment. One interpretation is that students who could not participate with an adult decided that they would not be able to do it on their own and did not attempt it.

A third contribution of this study is the demonstration of “what works” in a family engagement program. Epstein called for more studies on family engagement activities at various grade levels and for diverse populations of students, families, and teachers (Epstein, 1995) to better understand potential outcomes. Successful family engagement programs are highly dependent on contextual factors, so I will discuss those that may be relevant to the findings. One factor was that the researcher was the classroom teacher. For eight months before the intervention, I attempted to build relationships with the families through informative and respectful communications. Family-school partnerships are likely to be productive when educators include communications that show appreciation for the parents’ efforts, as shown in one nationally representative study (Park & Halloway, 2018). Secondly, this study was conducted in a grade six classroom where students and parents transition from an elementary school approach that includes more in-school parent involvement. At-home learning is an age-appropriate way that parents can stay involved in educational activities of their children (Halsey, 2005; Spera, 2005). Finally, the school is situated in a township whose population has above-average income and educational attainment. Previous research has shown that demographic characteristics affects the types of involvement in school and home-based educational activities (Lee & Bowen, 2006). The types of involvement exhibited by parents from dominant groups (European American homes, non-poor homes, and homes with more highly educated parents) had the strongest association with achievement. In particular, parent-child discussion occurred more frequently in the homes most likely to be culturally similar to the school. However, the parents from nondominant groups were in agreement about the importance of parent involvement, representing an opportunity to build on cultural assets. Inclusive school practices that acknowledge parent involvement as a shared value support productive partnerships (Lee & Bowen, 2006, Park & Holloway, 2018). This intervention deliberately included the message that the parent involvement was appreciated because families would be more likely to engage if they were told that by doing so, they would improve their children's educational experience. The intervention gave parents an opportunity to offer authentic and valuable support, as an alternative to traditional forms of homework help, which are not always helpful (Hill & Tyson, 2003). By helping to redefine "learning at home" (Epstein 1995) to mean "encouraging, listening, reacting, praising, guiding, monitoring, and discussing, not 'teaching,'" this intervention might support the learning outcomes suggested in both the Hoover-Dempsey and Sandler model and the Epstein model.

The potential outcomes from engagement such as that seen in this intervention fall into both proximal and distal categories. In the Hoover-Dempsey model, proximal learning attributes include student achievement, academic and socio-emotional learning, academic self-efficacy, intrinsic motivation to learn, self-regulatory strategy knowledge and use, and social self-efficacy for relating to teachers. In the Epstein model, family engagement in the form of learning at home potentially results in students' gains in skills, abilities, and test scores as well as a positive attitude toward schoolwork and self-concept. Interestingly, the Epstein model also identifies positive outcomes for the parents and the teachers as well.

The findings contribute to the theories of family engagement in three areas: (a) the actions of parents, (b) the perception of students, and (c) portraying effective elements of a school-home partnership and potential outcomes. The parents demonstrated Hoover-Dempsey and Sandler's (2005) encouragement, specific affective support for learning and reinforcement, in which students to rehearse and affirm their knowledge. The students' ambivalence to parent assistance contributes to our understanding of middle-schoolers' autonomy and may guide appropriate interventions for this developmental stage. Finally, this study provides evidence that family engagement in science learning activities can be supported and that these activities present opportunities for an array of positive learning outcomes. The activities were supported by specific guidance appropriate to the participants needs, offered in the context of a mutually respectful home-school relationship. The outcomes of the activities are a result of complex interacting factors, but may contribute to students' overall cognitive and social development.

Reflection on Challenges of At-home Learning

Two challenges of at-home family engagement appeared during this study. The first was the low overall rate of participation with parents, and the second was differential outcomes for girls. I perceive these as challenges because the predicted benefits of family engagement programs are not actualized if few students participate. Instead of resulting in more equitable participation, it may instead increase disadvantages for some students.

In regards to the first challenge, despite all of my reminders, only 21 of my 98 students completed it with parents. Despite typical middle-school complaints about the time that homework takes, the recordings were short, less than five minutes. Even if we double that by adding in the “getting ready time,” the whole assignment took less than fifteen minutes. It strikes me that there is a discrepancy between what students and parents and teachers perceive as meaningful homework. In addition to messages to parents about the importance of their engagement, it might be worthwhile to convince students of this.

In regards to the second challenge, fewer girls participated even though they represent an equal number of students in the classes. There were 8 girls (5 in Round 1 and 3 in Round 2) compared to 13 boys. Girls had less overall talk, the mean number of levels was lower, and the girls used fewer mid-level statements. Three responses by girls (1 in Round 1 and 2 in Round 2) met the criteria for high-quality compared to eleven by boys. These findings were disappointing. There are an array of factors, including self-selection and implicit bias that inhibit girls from participating in classroom discourse, especially in science (Howe 1997). However, I did not expect to see a clear effect in discussion at home. It is possible that the intervention was helpful to girls in other ways, for instance by maintaining girls’ interest in science (Heddy & Sinatra, 2017).

The closing of schools due to the COVID-19 pandemic in March 2020 have made these two issues, though outside the frame of the research questions, particularly salient. During at-home/virtual instruction in the spring of 2019, students in this district were expected to spend 30 minutes per day per subject. It seems likely that during a period of national stress, parents would be less likely to be available to help, and students might be even less likely to ask for help. Comments from parent surveys have indicated a preference for more effective and more time-consuming virtual instruction; however, the results from this intervention expose the difficulty of this charge.

The low rates of participation imply that some students are disproportionately impacted by school closures. I did not collect data on the ethnic, racial or socio-economic backgrounds of participants, but my impression is the students who submitted responses were not demographically representative of the school population. I had hoped that this intervention would be an effective way to build confidence of immigrant students, low-income students, and students of color. However, based on these findings, virtual instruction does not promise to be any more equitable than in-school science instruction.

Summary of the Design Changes

I employed design-based research methods to study the design and implementation of the intervention in order to explain how learning might occur in this setting (Design-Based Research Collective, 2003). Three conditions of a design experiment were met: It was extended (iterative), interventionist (innovative and design-based), and it addressed the interactions between the discourse, the participation and activity structures and the tools and materials. The class sections were presented the lessons sequentially, allowing for modifications to the tools and materials over two rounds of iteration. In this section I will explain what motivated the changes.

My notes on the lesson plan and class discussion reflected my concern that students did not have much to say about the first set of standard diagrams. Only a few students were willing to talk about them. I did not explicitly present these models as representations of student thinking. Students also did not connect the evidence we had gathered to the models. I decided to build time into Round 2 to collect student models and copy them into the MEL for Round 2.

From the recordings from the first round, I recognized that discussions were shorter than I expected. I examined the longest recording which indicated that the student and the parent had a preliminary conversation about the models before beginning the recording. I decided to add a question to the suggested prompts for Round 2: “Tell me about the models.”

Future iterations should incorporate other design changes. I suggest embedding the assignment in a more extensive program of class-home communication. It is possible that the increased number of parent participants in Round 2 can be attributed to the greater number of communications received by the parents. Both parent groups from Round 1 and Round 2 began receiving emails from the teacher at the same time, but the Round 2 group had two more emails before the specific assignment was given to students. These emails may have made the parents more familiar with the topics under study and raised their interest in participating. It is also possible that the low participation rate was an effect of the time allotted for the assignment. Perhaps more responses with parents would have been submitted if they had been given more than a week or if they had the option of one of several assignments over the course of the year.

In the year following the intervention, I sent short videos by email to the new parents of students in my class every three or four weeks explaining the topics and methods we were studying in science. Had we been able to continue regular instruction, I would have had students share their classwork and concluded the year with a similar family activity. When school was shut down due to the pandemic, I received positive feedback from parents that gave the impression that parents were comfortable with my ability to engage students in virtual learning. At the very least, creating the messages prepared me to deliver instructions using technology.

Limitations and Directions for Future Research

While the findings from this study illuminate learning as it occurs in this setting, the approach was specifically developed to this context and is not meant to be applied to other settings. The school is located in a town with a highly-educated population, within a state that frequently tops national lists of best schools. It is likely that the parents who participated were college graduates, had a higher income than the state average and had more free time to help their children. These parents represent a self-selected group with values and characteristics that limit the generalizability of the results.

Three other factors limit the generalizability of the findings. First, the students in these four classes were not eligible to receive special education such as ESL or disability services, though some had temporary or minor accommodations. The type of talk that was helpful for students in this situation should not be regarded as ideal for all students. Second, the number of responses represented less than 25% of the students. The responses from the other 74 students might be different from the 21 analyzed here. Thirdly, the responses were gathered at the end of the sixth grade year. Had the assignment been at the beginning of the year or from students in a different grade level, the responses would likely be different.

Researcher bias may also have affected the results. As the classroom teacher, I had many hours of listening and talking with my students that may have caused me to interpret their talk differently than if I had no prior contact with the students. The same is true of my relationship with some of the parents—my interpretation of their talk may have been affected by prior conversations. I took steps to mitigate my bias by not analyzing the results until after the school year ended and having a colleague code the responses with me.

Future research should focus on the wider array of outcomes that might be affected by students and parents working together. Expanded outcome measures should include student science achievement measures. Further, a future iteration of this intervention should incorporate student perceptions of assistance. This will make it possible to link the activities to outcomes such as academic and social self-efficacy, as well as a self-efficacy for relating to teachers.

Finally, a carefully designed study might also evaluate outcomes for parents. Epstein (1995) suggests that the expected results for parents include productive curriculum-related interactions with children. With this in mind, a future iteration of this study should also aim to have an impact on designing family engagement programs for social and educational equity.

Implications

A family engagement program should be designed to mitigate disparities rather than exacerbate them. Starting with an assessment of available resources and building on those strengths is likely to bring more positive results than imposing an intervention that implies a deficiency at home. The parents in this school district have made clear that communication with teachers and support for students was a priority. Knowing that the educational attainment of the parents in my district was high, I designed my study to build on what they appeared to already know, that is, traditional school talk. Future research should not assume that the talk used here is inherently better but instead should take a strengths-based approach and build on what parents already do.

This study addresses our need to understand how learning happens in real-world settings. In this dissertation, I aimed to offer insight into patterns of interaction between children and their parents in the context of scientific discussions. I examined the use of suggested questions, the use of the supporting materials, and student responses and supplemental adult questions. The suggested prompts for parents and the Model-Evidence-Links Matrix (MEL), were critical features of the intervention. These features, mediated by the active questioning approach, led to productive discourse as shown by high-quality responses.

The findings from this study could influence teaching and learning by helping practitioners understand the mechanisms and potential outcomes of productive discourse.

Through examination of high-quality responses, I have shown that teacher-provided scaffolds and parent questioning practices can help students to express complete explanations. By describing the interactions, I have contributed to the body of evidence that supports the significance of scientific discourse to learning.

As the digital learning tools become more varied and accessible, more opportunities for family engagement will become available. The description of this intervention and its limits may help future scholars build programs through which the benefits of parent-child interactions can be realized.

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Appendix A

Assent and Consent Documents

ASSENT FOR PARTICIPATION IN RESEARCH ACTIVITIES WITH AUDIO/VISUAL ADDENDUM

Investigator: Mrs. S. Miller
Rutgers University
Study Title: Discussing science at home and at school
This assent form may contain words that you do not understand. Please ask the researcher or your parent or teacher to explain any words or information that you do not clearly understand before signing this document.

1. **Mrs. Miller is inviting you to take part in his/her research study. Why is this study being done?**
The purpose of this research is to determine how interactions with parents affect students' use of evidence, justifications, rebuttals and counterarguments.

2. **What will happen**:
The students in your class will have regular assessments and the same activities that students in all Mrs. Miller's classes have. You might complete diagrams, read from texts and work in small groups. You will also complete a quiz on understanding models and an individual writing task. You will work with other students in pairs, small groups, as a whole class and sometimes independently. Mrs. Miller will video record what happens in the classroom during group discussion. Mrs. Miller will use these results to decide whether to change the activities to help you and your fellow students learn more.

   In addition, Mrs. Miller will ask you to use your Chromebook for a homework assignment. If you cannot do the assignment on the night it is assigned, or the Chromebook does not work, the homework will not count against your grade.
.

3. **What does it cost and how much does it pay?**
You don't pay to take part in this study and Mrs. Miller will not pay you.

4. **There are very few risks in taking part in this research, but the following things could happen**:

   Probably: Nothing bad would happen.

   Very unusual: Your work or the recordings would be seen by somebody not involved in this study. We will do our absolute best to keep all your responses private. Your responses will be kept locked up. Your name will not appear on the recordings; we will use a code number instead. Mrs. Miller is very well trained and understands the importance of confidentiality. But, if Mrs. Miller learns that you or someone else is in serious danger she would have to tell an appropriate family member, such as your mother, father, or caretaker or the appropriate officials to protect you and other people.

5. **Are there any benefits that you or others will get out of being in this study?**
All research must have some potential benefit either directly to those that take part in it or potentially to others through the knowledge gained. You may not directly benefit, but the knowledge gained through this study may allow us to develop more effective ways to help students learn science.

   It's completely up to you! Both you and your parents have to agree to allow you to take part in this study. If you choose to not take part in this study, we will honor that choice.
No one will get angry or upset with you if you don't want to do this. If you agree to take part in it and then you change your mind later, that's OK too. It's always your choice!

6. **CONFIDENTIALITY: We will do everything we can to protect the confidentiality of your records.** This research is confidential. The research records will include some information about you/your child and this information will be stored in such a manner that some linkage between you/your child's identity and the response in the research exists. Some of the information collected about you/your child includes name, ethnicity, results from science assessments. Please note that we will keep this information confidential by limiting individual's access to the research data and keeping it in a secure location. We will use the security measures we use in school: keeping student work in a locked filing cabinet, locking the classroom door when the teacher is not present, using a password for the laptop and backup drive.

The research team and the Institutional Review Board (a committee that reviews research studies in order to protect research participants) at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. No linkage between a participant's identity and his or her responses will be revealed. All study data will be kept for six years.

Do you have any questions? If you have any questions or worries regarding this study, or if any problems come up, you may call the principal investigator Mrs. Miller at smiller@warrentboe.org, 908-753-5300 x6061, or 100 Old Stirling Road, Warren, NJ 07059 or Dr. Clark Chinn, Graduate School of Education, Department of Educational Psychology, (848) 932-0824, clark.chinn@gse.rutgers.edu

If you have any questions about your rights as a research subject, you may contact the Institutional Review Board (a committee that reviews research studies in order to protect those who participate). Please contact an IRB Administrator at the Rutgers University, Arts and Sciences IRB:

Institutional Review Board
Rutgers University, the State University of New Jersey
Liberty Plaza / Suite 3200
335 George Street, 3rd Floor
New Brunswick, NJ 08901
Phone: 732-235-2866
Email: humansubjects@orsp.rutgers.edu

Your parent or guardian will also be asked if they wish for you to participate in this study. You will be given a copy of this form for your records.

Please sign below if you assent (that means you agree) to participate in this study.

Name of Minor Subject (Print) ____

Minor Subject's Signature ___________________ Date ______________________

Principal Investigator Signature _____________________ Date __________________

AUDIO/VISUAL ADDENDUM TO CONSENT FORM

You have already agreed to participate in a research study entitled: Discussing science at home and at school conducted by Mrs. S. Miller. We are asking for your permission to allow us to audiotape, photograph, and videotape as part of that research study. You do not have to agree allow us to photograph and/or record in order to participate in the main part of the study.

The photographs and recording(s) will be used for analysis by the research team

The photographs and recording(s) will include full facial pictures.

The photographs and recording(s) will be stored in a password-protected electronic file and a locked file cabinet and linked with a code to subjects' identity and will be kept for six years

Your signature on this form grants the investigator named above permission to record you as described above during participation in the above-referenced study. The investigator will not use the recording(s) for any other reason than that/those stated in the consent form without your written permission.

Please sign below if you assent to allow the investigator to record you for this study.

Name of Minor Subject (Print) ____

Minor Subject's Signature ___________________ Date ______________________

Principal Investigator Signature _____________________ Date _________________

PARENTAL INFORMED CONSENT

Investigator: Mrs. S. Miller
Rutgers University
Study Title: Discussing science at home and at school
You are invited to participate in a research study that is being conducted by Mrs. S. Miller, who is a student in the Graduate School of Education at Rutgers University. The purpose of this research is to determine how interactions with parents affect students' use of evidence, justifications, rebuttals and counterarguments.

Approximately 77 subjects will participate in the study, and each individual's participation will last approximately 3 weeks.

The study procedures include classwork, discussion, homework and assessments. Mrs. Miller will follow the district's approved curriculum for grade six science. Students will use typical text and web-based resources in this unit. Students will make observations, ask questions about geologic features and events, obtain and compare information from different sources, develop explanations, and make predictions about events in the future or in other settings. They will work together in pairs, small groups, as a whole class and sometimes independently. Students will be taught how to summarize evidence and describe how the evidence supports or contradicts proposed models. Students share their ideas with each other and with the teacher, in whole class discussions and in small groups. The teacher uses these discussions to assess student understanding and to plan further instruction to help students meet learning objectives. Homework is assigned a few times per week and may include defining vocabulary, completing a review game, watching a short video or reading and answering comprehension questions.
Class discussion will be videotaped. For some homework assignments students will record their oral explanation. You may be asked to help your child as he or she thinks about their explanation.

This research is confidential. Confidential means that the research records will include some information about you/your child and this information will be stored in such a manner that some linkage between your/your child's identity and the response in the research exists. Some of the information collected about you/your child includes name, ethnicity, results from science assessments. Please note that we will keep this information confidential by limiting individual's access to the research data and keeping it in a secure location. We will use the security measures we use in school: keeping student work in a locked filing cabinet, locking the classroom door when the teacher is not present, using a password for the laptop and backup drive.

The research team and the Institutional Review Board at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. No linkage between a participant's identity and his or her responses will be revealed. All study data will be kept for six years. All study data will be kept for six years.

There are no foreseeable risks to participation in this study.

You/your child have been told that you may receive no direct benefit from taking part in this study.

Participation in this study is voluntary. You may choose for your child not to participate, and you may withdraw your child from participating at any time during the study activities without any penalty to your child. In addition, you/your child may choose not to answer any questions with which you/your child are not comfortable.

If you/your child have any questions about the study or study procedures, you/your child may contact myself at smiller@warrentboe.org, 908-753-5300 x6061, or 100 Old Stirling Road, Warren, NJ 07059 or Dr. Clark Chinn, Graduate School of Education, Department of Educational Psychology, (848) 932-0824, clark.chinn@gse.rutgers.edu

If you/your child have any questions about your rights as a research subject, you may contact the Institutional Review Board (a committee that reviews research studies in order to protect those who participate). Please contact an IRB Administrator at the Rutgers University, Arts and Sciences IRB:

Institutional Review Board
Rutgers University, the State University of New Jersey
Liberty Plaza / Suite 3200
335 George Street, 3rd Floor
New Brunswick, NJ 08901
Phone: 732-235-2866
Email: humansubjects@orsp.rutgers.edu

Your child will also be asked if they wish to participate in this study. You will be given a copy of this consent form for your records.

Sign below if you agree to allow your child to participate in this research study:

Name of Child (Print) ____

Name of Parent/Legal Guardian (Print) ____

Parent/Legal Guardian's Signature ___________________ Date ______________________

Principal Investigator Signature _____________________ Date __________________

AUDIO/VISUAL ADDENDUM TO CONSENT FORM

You have already agreed to allow your child to participate in a research study entitled: Discussing science at home and at school conducted by Mrs. Simone Miller. We are asking for your permission to allow us to audiotape, photograph, and videotape your child as part of that research study. You do not have to agree allow your child to be photographed and/or recorded in order to participate in the main part of the study.

The photographs and recording(s) will be used for analysis by the research team.

The photographs and recording(s) will include full facial pictures.

The photographs and recording(s) will be stored in a password-protected electronic file and a locked file cabinet and linked with a code to subjects' identity and will be kept for six years.

Your signature on this form grants the investigator named above permission to record your child as described above during participation in the above-referenced study. The investigator will not use the recording(s) for any other reason than that/those stated in the consent form without your written permission.

Name of Child (Print) ____

Name of Parent/Legal Guardian (Print) ____

Parent/Legal Guardian's Signature ____________________ Date ________________

Principal Investigator Signature _____________________ Date __________________

Appendix B

Scripts for Parent Invitation Video - Round 1 and 2

Link to Invitation video

Round 1

Thank you for sharing your earthquake stories. The children were able to connect the stories to the magnitude or strength of an earthquake.

We also used several models to demonstrate different types of seismic waves.

Our next unit builds on our understanding of the surface of the earth by tackling plate tectonics.

I have always felt very lucky to be teaching in a place where parents care so much about education, and are so dedicated to helping their kids.

My students are curious and enthusiastic learners. And as their parents, you're the reason.

I wonder what it is that you do to make them so capable, and as part of my ongoing education in education, I've come to think that it has something to do with how you talk to them about learning. By "Talk" I mean the social interaction that comes from sharing what you know and subjecting it to critique by others. It's an important part of all disciplines, including science.

This has been a concern of mine for quite a while and I hope I can ask for your help.

My idea is that it's the type of talk that you engage in that makes the difference in kids learning.

I am proposing a study that will find out what parents do to make their children talk about science productively and develop ways to support these interactions.

To address these goals, I am asking for your consent to use the children's next flipgrid assignment, which will come in May. I will also ask you to work with your child as they do the assignment. It should take no more than 10 minutes.

You'll be receiving a consent form – electronically, in a separate message. If you agree, and change your mind later, that's ok. When the assignment comes home, in May, I will provide additional instructions and guidance. If you have any questions, please get in touch. No child's grade will be affected by whether or not parents participate.

One other thing you might be worried about – not knowing the answer. The good news is, you are not alone. That's one of the benefits of this study, being able to help educators develop ways to make parents feel capable of helping their kids.

A second benefit, is that kids actually learn by teaching you. Your role is to ask thinking questions, the same way you probably already do when you ask them about a book they've read or a how they figured out the change from a purchase.

Thank you again for all of your support.

Round 2

Thank you for sending back the permission slips for our field trip next month.

I have always felt very lucky to be teaching in a place where parents care so much about education, and are so dedicated to helping their kids.

My students are curious and enthusiastic learners. And as their parents, you're the reason.

I wonder what it is that you do to make them so capable, and as part of my ongoing education in education, I've come to think that it has something to do with how you talk to them about learning. By "Talk" I mean the social interaction that comes from sharing what you know and subjecting it to critique by others. It's an important part of all disciplines, including science.

This has been a concern of mine for quite a while and I hope I can ask for your help.

My idea is that asking kids to explain what they are learning can improve their understanding.

I am proposing a study that will find out how parents can help their children talk about science productively and develop ways to support these interactions.

To address these goals, I am asking for your consent to use the children's next video homework assignment, which will come in May. I will also ask you to work with your child as they do the assignment. It should take no more than 10 minutes.

You'll be receiving a consent form – electronically, in a separate message. If you agree, and change your mind later, that's ok. When the assignment comes home, I will provide additional instructions and guidance. If you have any questions, please get in touch. No child's grade will be affected by whether or not parents participate.

One other thing you might be worried about – not knowing the answer. The good news is, you are not alone. That's one of the benefits of this study, being able to help educators develop ways to make parents feel capable of helping their kids.

A second benefit, is that kids actually learn by teaching you. Your role is to ask thinking questions, the same way you probably already do when you ask them about a book they've read or a how they figured out the change from a purchase.

Thank you again for all of your support.

Appendix C

Script for Parent Instructional Video (how to use talk prompts) - Round 1 and 2

Link to video

Round 1

Yesterday, I shared with the students the goals of my study and asked for their cooperation. I also told them about the safeguards to respect their privacy.

I wanted to take another opportunity to inform you of what I'm asking. You can use this information over the weekend to decide if you are willing to participate.

The students' assignment will be to explain their reasons for choosing one model over another. In science, a model can be a physical representation of a theory or idea, like a model for a volcanic eruption, but it must **explain or predict natural phenomena.**

In school, we use the term "scaffold" to mean a technique that helps a student reach a learning objective that is out of their grasp, until they are able to do it on their own.

An example is a visual cue, like a poster, or reminders, like the morning announcements.

I have recently introduced a scaffold called the "MEL" to help them evaluate and choose a model.

To show how to use it, we investigated a case of a grocery store burglary.

The MEL helps us analyze the evidence to decide whether Sam is Guilty or Not Guilty.

For each piece of evidence, the students use arrows to indicate whether it "supports" or "contradicts" the models.

For example, students might say that evidence #1 supports both models and use two arrows.

They also might decide that evidence #4 is irrelevant and use two dashes

And that Evidence #5 contradicts one model but supports the other.

Using this tool, the students understand that the evidence by itself is not enough -- that they have to give reasons and explanations to connect their evidence to their model.

It also helps them realize that any one piece of evidence by itself might tell a different story that the body of evidence as a whole.

So, again, don't be concerned about whether your child, or you, have the "right" answer. The point is that students must explain their thinking.

If you have any questions, please get in touch. The consent form is attached to this message. The assignment will come home next week.

Round 2

Last week we (reference to a student) making posters and participating in the walk.

I also shared with the students the goals of my study and asked for their cooperation. I also told them about the safeguards to respect their privacy.

The students' assignment will be to explain their reasons for choosing one model over another. In science, a model can be a physical representation of a theory or idea, like a model for a volcanic eruption, but it must **explain or predict natural phenomena.**

In school, we use the term "scaffold" to mean a technique that helps a student reach a learning objective that is out of their grasp, until they are able to do it on their own.

An example is a visual cue, like a poster, or reminders, like the morning announcements.

I have recently introduced a scaffold called the "MEL" to help them evaluate and choose a model.

To practice using it, we investigated a case of a grocery store burglary. The MEL helps us analyze the evidence to decide whether Sam is Guilty or Not Guilty.

For each piece of evidence, the students use arrows to indicate whether it "supports" or "contradicts" the models.

For example, students might say that evidence #1 supports both models and use two arrows.

They also might decide that evidence #4 is irrelevant and use two dashes

And that Evidence #5 contradicts one model but supports the other.

Using this tool, the students understand that the evidence by itself is not enough -- that they have to give reasons and explanations to connect their evidence to their model.

It also helps them realize that any one piece of evidence by itself might tell a different story that the body of evidence as a whole.

1. Tell me about the models
2. Which model is better supported? (and why?)
3. What would you say to someone who thought another model was better?
4. What evidence is most useful?

Again, don't be concerned about whether your child, or you, have the "right" answer. The point is that students must explain their thinking. Your student should be familiar with responding to questions with sentence starters such as "My evidence is.."

If you have any questions, please get in touch. The consent form is attached to this message. The assignment will come home next week.

Appendix D

Reference Sheets for Parents - Round 1 and 2

Round 1 Flowchart

QUESTIONS

1. CONNECT

Which model are you thinking of eliminating?

How did you decide to eliminate that one?

2. CONNECT

Which models are you thinking you should keep?

3. CLARIFY

Which model do you think is  a better fit?

CHEER 'EM ON

Be curious. Let your child know that you're interested in what we're learning.
Give your child a chance to be the expert. Even if you think they're on the wrong track, resist the urge to correct them.

Get comfortable. Use the language that you would usually use and ask the questions that you think up. This guide is meant to support, not replace, the conversations you may already be having.

Cut it short. The talk should take 5 to 10 minutes. You don't have to finish all the questions.

Round 2 Talk Prompts

Conversation Starters

1. Tell me about the models

2. Which model is better supported? (and why?)

3. What would you say to someone who thought another model was better?

4. What evidence is most useful?

Have Fun!

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- **Give your child a chance to be the expert.** Even if you think they're on the wrong track, resist the urge to correct them.
- **Get comfortable**. Use the language that you would usually use and ask the questions that you think up. This guide is meant to support, not replace, the conversations you may already be having.
- **Cut it short**. The talk should take about 15 minutes. You don't have to finish all the questions.

Mrs. Miller, WMS 6th grade Science

Appendix E

Instructional Plan

Unit	Inside the Earth II
Grade Level	6
NGSS Performance Expectation(s)	**MS-ESS2-3.** **Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.** [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches)
NGSS Scientific Practices)	Developing and Using Models Analyzing and Interpreting data Obtaining and Evaluating Information Constructing Explanations
NGSS Crosscutting Concepts	Patterns Cause and effect Systems and system model
NGSS Disciplinary Core Ideas	**ESS1.C: The History of Planet Earth** • Tectonic processes continually generate new ocean sea floor at ridges and destroy old sea floor at trenches. *(HS.ESS1.C GBE),(secondary to MS-ESS2-3)* **ESS2.B: Plate Tectonics and Large-Scale System Interactions** • Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart. (MS-ESS2-3)
Duration:	11 days
Disciplinary core idea progressions	Before Grade 6: Earth's physical features occur in patterns, as do earthquakes and volcanoes. Maps can be used to locate features and determine patterns in those events. In Grade 6-8: Plate tectonics is the unifying theory that explains movements of rocks at Earth's surface and geological history. Maps are used to display evidence of plate movement.

	In Grades 9-12: Radioactive decay within Earth's interior contributes to thermal convection in the mantle What we know from prior lessons
Anchoring phenomenon:	*Axial Seamount Underwater Volcano Erupting Off Oregon (2015)*
Plate Tectonics concept chart Activity/evidence list for students student handouts plate tectonics example explanation/model	

Day 1: Engage

Concepts: The crust is broken into plates. Earthquakes occur at the edges of the plates and show us where they are. Volcanoes are tectonic processes.

Summary:

1. Introduce guiding question: What can volcanoes tell us about how plates are moving?
2. Introduce anchoring phenomenon: underwater volcanoes
3. Introduce objective: Explain how the Axial seamount come to be where it is.
4. Draw a model of what might be happening inside Earth to cause the volcano to form.

Learning Activities		**Teacher**	**Student**
Initiate – 5 minutes	View Alaska earthquake and volcano case study View *Axial Seamount Underwater Volcano Erupting Off Oregon (2015)*	Introduce guiding question: "What can volcanoes tell us about how plates are moving?" Introduce anchoring phenomenon: underwater volcanoes. Invite student questions and reactions to the videos.	Earthquakes tell us where plate boundaries are. Places where there are earthquakes also have volcanoes
Develop – 25 minutes	View eruption of West Mata *(2009)* discovery of the erupting deep-ocean volcano West Mata *2009)* Use natural hazards viewer to	In whole class (w/c) setting, ask, "what can volcanoes tell us about how plates are moving?" Ask students what questions they have and elicit observations. Ask each student to write one sticky note. In small groups (s/g), ask students view current eruptions	Students write observations of eruptions and earthquake patterns on sticky notes. Students use SI to observe current volcanic eruptions Students write four notes from their own or from the group onto observation chart.

	zoom into Aleutian Islands, Mt. St. Helens and Yellowstone and Axial.	and then to share their observations. Tell students "Our observations can help us answer our questions: What are volcanoes? How do they erupt? What causes them to form? Where do volcanoes form? What can volcanoes tell us about plate movement?" Tell students "Our objective is to explain what might be contributing to or causing the Axial volcano to be located where it is. Let's create list of hypotheses that we have so far." Write down student ideas on projection. Next, in small groups (s/g) ask students to draw a model of what might be happening inside Earth to cause the Axial seamount to form. Ask students to draw on the back of observation chart and add title, labels.	Students suggest possible explanations for the formation of Axial. As a small group (s/g), students diagram and label on paper. Each student keeps a paper copy.
Closure – 10 minutes	Summarize observations	Tell students: "To help us create the model that best explains what could be happening to create Axial, we will use science practices -- obtaining information, analyzing and interpreting data, developing and using models. We will keep a list of the evidence we gather. Today we observed:" use student sticky notes to write observations on projection. Write these statements on a class summary table to post in the front of the room. Solicit students' ideas about how it helps us understand Axial.	In a whole class setting, students take turns writing observations in the "what we saw" column. Students write "Volcanoes are related to earthquakes. They are formed by forces from inside the earth (tectonic processes). Most volcanoes occur in bands that are often along the boundaries between continents and oceans. Alaska's Aleutian islands are a chain of volcanic mountains." In the "how it helps explain" column, write "Axial is erupting on a plate boundary between the Pacific and Juan de Fuca plates at the bottom of the ocean (not on the coast)"
Student supports: In Google Classroom, post Smithsonian Institute link. Student worksheets: Observations & Initial explanatory models			

Day 2: Explore

Concepts: Volcanoes form both on land and at the bottom of ocean. Sometimes they form islands. Some volcanoes are near trenches. Some volcanoes form at places where new rock is being formed. Other volcanoes are on land near places with older sea-floor.

Objective: Analyze data from volcanoes, topography and age of seafloor.

1. How are volcanoes related to other landforms and age of the sea floor?
2. Introduce evidence summary table
3. Translate observations into evidence

Activities	**Teacher**	**Student**
Initiate – 5 minutes Review objective	Tell students: "Yesterday, we noted that Axial is erupting on a plate boundary between the Pacific and Juan de Fuca plates at the bottom of the ocean (not on the coast)." (Project this wording on the board). Some volcanoes occur on the bottom of the ocean. As we found with hurricanes, sometimes the location of a catastrophic event can give us clues to help us explain how and why it occurs. Today we're going to look at two maps and compare each to the volcano map. Your job is to examine two maps at the same time and find connections between them. You'll write two sticky notes. Each one should make a link from one map to the other. At the end of 10 minutes, we'll discuss our observations and use them to summarize what we found out about Axial. At the end of today's activities, we'll be able to answer these questions: How are volcanoes related to other landforms like mountains? How are volcanoes related to age of the sea floor?"	
Develop – 25 minutes Compare maps to determine "How are volcanoes related to other landforms and age of the sea floor?" Compare volcano map/topographic map	Show first volcano map on smartboard. Ask for suggestions on what each red dot means. Explain that not all volcanoes are on the map, just the ones that are above water. Display topographic map and ask questions about the legend. Point out that the colors indicate elevation. Generate an example of a WIS observation such as "There are few volcanoes near us." Point out that there are mountains near us. Ask students: "Where are there connections between the two maps?" Ask students to look closely at the edge of the Caribbean for volcanoes. As students work in s/g, circulate to each group. Listen for one minute, then ask a "leaving question." "I hear you are making great observations, I want to leave you with one question that you can help the whole class see." Sample questions. Where are the higher points? Are all mountains are also volcanoes? Where are the tallest mountains? Where are the deepest parts of the ocean? What do you notice about volcanos in the Atlantic? Where is Axial in relation to the "Ring of Fire?" Are there any other volcano on the map similar to Axial? Collect topographic map and distribute second map of age of sea-floor. Remind students to follow procedure: look for title, examine key, notice similarities and differences	In s/g, on the topographic map, each student should write two post it notes. Sample: "The area of higher elevations between the Indian subcontinent and Asia (Himalayas) on the topographic map do not show volcanoes." Each student should contribute two WIS notes to seafloor map. An example of a WIS might notices the age of sea-floor around Iceland is younger than the area farther away.

	between maps. Display map on projector, review key carefully. Visit small groups to find groups who have identified that some volcanoes occur near old rock (Aleutian islands) and some volcanoes, like Axial, are surrounded by new rock. Ask students to prepare to share with the rest of the class.	
Closure – 10 minutes Summarize evidence and solicit ideas for how it explains Axial.	Closure: Hand out evidence summary table with yesterday's evidence pre-printed. Summarize evidence while students add to the chart. In the "evidence column," students write "Volcanoes form both on land and at the bottom of ocean. Sometimes they form islands. Some volcanoes are near trenches. Iceland is part of a chain of volcanoes. Rocks increase in age with distance from the line of volcanoes around Iceland. The seafloor around Axial is younger than the seafloor farther away." Ask: "How does what we've learned in this activity help us explain Axial?"	In the "how it helps explain" column, students write: "Axial is an undersea volcano with surrounded by young rock similar to Iceland."
Student supports: In Google Classroom, post magnetism video to refer students who ask about dating rock. Student worksheets: Summary table Public Records: Post Hypotheses List and Summary Table		

Day 3: Explore		
Concept: Scientific models are developed to predict and/or describe phenomena and used to describe unobservable mechanisms. **Objective:** Develop a model that explains how Axial came to be where it is. 1. Review preliminary hypotheses 2. Using observations, draw group model 3. Critique models		
Activities	**Teacher**	**Student**
Initiate – 5 minutes Introduce objective	Tell students "Today we're going to come up with a scientific model that can help explain our observations from the maps of the last two days. Our initial model, the one you drew in your notebook, can be revised as we gather more data. At the end of class, each group will have a model and will share it with the class."	Students look at their Evidence Summary Table.
Develop – 25 minutes Sort claims Discuss hypotheses. Draw group model	Ask students: "What is our explanation for this evidence? Are there any ideas we can rule out?" Show students claim cards. Tell students "Here are some statements that might help us develop our explanations. Sort through these with your group and decide which statements are supported by the evidence we have so far, and which need more data, and which may be untrue. Let's make three columns." Circulate among the groups. Remind them of the importance of evidence in science. Listen to each group. Find a group that has identified that because volcanoes also occur in cold climates (Iceland, Alaska), we can cross off the connection to climate.	In s/g, students sort claims into those that are supported by the earthquake and sea floor evidence, those that are contradicted and those that do not have enough evidence. In s/g on poster paper, students create a model of what might be happening inside Earth to cause the

	Because we don't yet know how earthquakes and volcanoes are related, we can put those two statements in a column that "needs more evidence." Tell students, "Now that we have some observations and have connected those to the Axial seamount, let's see if we can eliminate some of our initial hypotheses." Look at the class hypothesis list and ask students to put an X next to those related to climate. Tell students, "Now let's consider what our model of Axial has to explain. Use class evidence table to write a list of things the model has to explain." Include age of sea floor, mountains and trenches. Ask students to draw a group model. Include both observable and unobservable features. Tell students you want to see everyone's handwriting somewhere. Visit each group asking questions: "Who can explain what this part of the diagram represents?" Can you give an example of where this might be happening? "What do you think is happening here?" "Can you tell me more about that?"	Axial seamount to form. Add title and labels. Using Flipgrid, record one spokesperson describing the parts of the model.
Closure – 10 minutes Assign homework (flipgrid)	For homework, look at two models from this class. Compare the model to the evidence summary table. Respond with "Two stars and a wish: I like that you (praise), I wish you had (suggestion)" To get started, think about "What do you notice that they included" 'Where do you feel you would like more detail or explanation?" "what did they not include? "Do you find any parts unclear or confusing?" "What would you do on the next draft if this were yours? or "What would you change?" Have one student create an example response for the class.	

Student supports: In Google Classroom,
Student worksheets: Summary table
Public Records: Post Hypotheses List and Summary Table
Materials: These statements are presented to students on individual cards, one set per group of 3-4 students.

- Earthquakes occur more often in some places than others (C)
- Volcanoes only occur in warm climates (X)
- Earthquakes occur in both cold and warm climates (C)
- Volcanic eruptions are usually followed by earthquakes (more evidence)
- Earthquakes cause most volcanic eruptions (more evidence)
- Earthquakes and volcanoes show similar patterns in their locations (C)
- Earthquakes and volcanoes always occur at or near tectonic plate boundaries
- Volcanoes make new rock (C)
- Earthquakes often occur near mountains (C)
- Deep-sea trenches are often near volcanoes ©
- Some places in the ocean are deeper than others. (C)

- Shallow parts of the ocean are always near land. (X)
- Earthquakes and volcanoes can occur in the ocean far from land (C)
- Earthquakes and volcanoes are found on every continent, including Antarctica (C)

<table>
<tr><td colspan="3"><u>Day 4: Explain</u></td></tr>
<tr><td colspan="3">Concepts: Volcanoes are associated with different depths of earthquakes. Subduction zone causes earthquakes and volcanoes.

Objective: Analyze data of earthquake depth and volcanoes
1. How are volcanoes related to the depth of earthquakes?
2. Map and define "subduction zone," using earthquake depth profile and animation
3. Modeling with foam pads</td></tr>
<tr><td>Activities</td><td>Teacher</td><td>Student</td></tr>
<tr><td>Initiate – 5 minutes
Introduce question</td><td>Show students News report of eruption in Chile. Tell students "Yesterday, we drew our model for the formation of the Axial seamount. We have gathered some evidence that might help explain how it came to be there. But we still have some gaps. We noticed that Axial is similar to Iceland, which is both a volcano and an island, but is very different from other volcanoes, like Mt. St. Helens, and different from other islands, like the Aleutian islands. What they all have in common are earthquakes, but not exactly the same kind of earthquakes. Today we're going to see what earthquake data can tell us about those places and add to our model for Axial.</td><td></td></tr>
<tr><td>Develop – 35 minutes
Compare earthquake depth map to volcano map

Describe collision zones and subduction</td><td>Can you make an observation of what's different about the earthquakes near Axial and those near the other two places? Hand out volcano map and earthquake depth maps in color on paper (from Discovering plate boundaries). Tell students to examine the legend for the earthquake map first. Ask students to make one note per person.
As students work in s/g, project these questions on the board: How are earthquakes distributed? If there is a pattern, how would you describe it? Where are there no earthquakes? Are they located near the edges of the continents, mid-continent, in the ocean? At what depth(s) do the earthquakes occur? (hint: look at the legend).
Visit each group listening for students who can answer these questions.
After each member has contributed an observation from the earthquake map, distribute the volcano map and ask students to consider: How are volcanoes related to the earthquakes at this location? As they work in s/g, visit groups and ask How does this data fit with the earthquake depth map? Can you give a specific</td><td>Groups will work on one of three locations. Students will count off by 3s, so two students from each table of 6 will be working on each location (n=8). Students in group 1 will have maps of Iceland, students in group 2 will have maps of the western South America (Chile) and students in group 3 will have maps of Alaska.

Students work in s/g to complete worksheet copying their own map.

Students draw vectors on their maps.

Students add terms and definitions to key terms sheet.</td></tr>
</table>

	example? Do you think that is strong evidence for any of the hypothesis? Does it rule out any? Identify students who have ideas about the relationships between earthquake depth and volcanoes. In w/c discussion, ask the students to describe their observations using a projected map. Begin with the Chile group, then the Alaska group. The students should notice that near in these locations, shallow earthquakes occurring on both sides of the plate boundary and intermediate and deep earthquakes occurring on one side of the boundary). Ask students what they think might be happening. When the students suggest a collision, ask how scientists might know if two locations are moving towards each other. Project the GPS station slides. Tell students that because of GPS stations like this one, geologists can detect how two locations are moving, and at what rate. GPS stations are anchored into rock or deep into soil so we can see how the whole area is moving. If the GPS stations are moving, then the ground is moving. Explain that a velocity vector is a special kind of arrow that shows the direction and speed of an object. Each vector arrow originates at a GPS station, and points in the direction that the station is moving. Its length is proportional to the station's speed (velocity). The longer the arrow, the faster the GPS and ground is moving. Ask students: What do you notice about the length of the vectors (the velocities) in the Pacific Northwest compared to those in coastal California? What direction(s) do the vectors point in the Pacific Northwest and California? What does this indicate? What other areas do you notice that have differing directions? What do you think is happening in these regions to cause these differences? Show students the subduction zone profile for Atka or Kodiak and then the elevation profile for Aleutian Islands, Cascades and Chile. Notice the deep ocean trench off the coast of the continent. Project animation that shows one plate sliding under the other. Define the word "subduction" for students. Show animation of changes over millions of years.	
Closure – 5 minutes Summarize evidence.	Closure: Volcanoes can form at plate boundaries where two plates are colliding. The collision boundaries are called subduction zones, where deeper earthquakes occur on one side and shallow earthquakes on the other side of the plate boundary, forming a deep sea trench at the ocean	Add to class summary table.

	floor because one plate is sliding under the other. Do not add yet to the "how does it explain" column.	
Materials: maps in color on paper (from Discovering plate boundaries) Student supports: In Google Classroom, post animation that shows one plate sliding under the other and animation of changes over millions of years. Student worksheets: Evidence Summary table Public Records: Post Hypotheses List and Evidence Summary Table		

Day 5: Explore		
Concept: Continents are continually being shaped and reshaped by competing constructive and destructive geological processes **Objective:** Contrast volcanoes on land to underwater volcanoes. 1. Show vectors for Iceland 2. Compare Iceland, Aleutian Islands and Chile to Axial		
Activities	**Teacher**	**Student**
Initiate – 5 minutes. Contrast Iceland to Chile and Cascades	Show national geographic Iceland video. Ask for student reactions, particularly about geo-thermal energy	Students share what they know about Iceland and geothermal energy
Develop – 25 minutes	Ask students for possible explanations for what's happening in Iceland. Ask the Iceland students to report on their observations. Near Iceland students notice that earthquakes are shallow, less than 33 km and shown as red dots. They occur on the plate boundary, not offset to one side or the other. Ask students to use foam pads and a gap to demonstrate the collision of two plates with different characteristics. As students are working in s/g, ask "What do you think would show up on the surface of earth when the plates move together and separate?" "Do you think the Earth is getting larger, if the plates are separating?" "If not, how could we test the idea that old crust is getting pushed down into the mantle?	Students to return to their original group (n=6). Students demonstrate their proposed explanations with foam pads (procedures for Inquiry 15.1 & Key) Students answer reflection questions

Closure – 10 minutes Summarize evidence	Summarize evidence from Day 4 & 5. "Volcanoes can form at plate boundaries where two plates are colliding. The collision boundaries are called subduction zones, where deeper earthquakes occur on one side and shallow earthquakes on the other side of the plate boundary, because one plate is sliding under the other. Old crust is destroyed at subduction zones." In the "what it means column," write "Axial is NOT at a subduction zone, but there is a subduction zone on the other side of the Juan de Fuca plate where it converges with the North American plate. The subduction zone includes a oceanic trench and the Cascades mountain range (Mt. Hood, Mt. St. Helens"	Students write evidence and "how it explains"
Materials: foam pads, procedures for Inquiry 15.1, Key Student supports: In Google Classroom, post Iceland video Student worksheets: Evidence Summary table Public Records: Post Hypotheses List and Evidence Summary Table		

Day 6: Explain		
Concept: New oceanic crust forms during the process of seafloor spreading at a mid-ocean ridge **Objective:** What does the pattern of earthquakes explain about Axial? 1. Revise models based on evidence 2. Exit ticket: under the sea		
Activities	**Teacher**	**Student**
Initiate – 5 minutes. Introduce question	Project the earthquake map from the Pacific Northwest. Ask students if they can use what they know about the three locations and the foam pads to determine what's happening at Axial. Ask students to make a claim about which pattern of earthquakes most resembles Axial	Students make claims about Axial as a result of collisional or divergent forces.
Develop – 25 minutes	In w/c discussion, ask how does new crust form? What would you expect to see at the bottom of the ocean where new crust is forming? Discuss article and ask what did Marie Tharp's maps look like? Show physical map of the ocean floor. Point out depth/elevation of Mid-Atlantic ridge. How did this help the theory of plate tectonics? Show video. What additional evidence could we use to make our claim stronger? Show vectors using the UNAVCO velocity viewer. Bring students' attention to what direction the arrows are pointing (the direction the ground is moving) and the lengths of the vector arrow (velocity).	Students respond to oral questions: What do you notice about the direction of the vectors) at Axial and Iceland compared to those in Alaska and Chile? What does this indicate? Students use the age of the sea floor map to answer the question: where does the crust at Axial subduct?" In s/g, students revise models with subduction and sea-floor spreading.

	Visit s/g to ask, "what do you think happens at Axial?" Ask students to consider that the plates are spreading apart at Axial, and colliding at Alaska, where does new crust forms? What happens at Aleutian islands? Old crust destroyed. Ask w/c to look at class models. Gather ideas about what's missing, what the initial models do not explain. Does the model show old crust going back into the Earth? Does it show how some earthquakes are deeper and some shallower? Does it show newer crust and older crust? Does it show volcanoes on land and oceans? Begin a checklist that specifies that the model must: define the components (parts of Earth, oceans and continents), use data (earthquake depth and sea-floor age), include both volcanic mountains on land and undersea volcanoes.	Each student in a group visit other groups' models look for one particular aspect from the gotta-have it list. After the visits to other groups, students incorporate ideas from other groups into their own model.
Closure – 10 minutes Summarize evidence and give exit ticket	Summarize evidence from day 6. "Volcanoes and a line of shallow earthquake indicate that plates are separating and magma is erupting on the bottom of the ocean, cooling and forming new rock." In the "how does it explain" column, write "Axial is located at a divergent (moving apart) plate boundary, where magma rises up to the surface and forms new crust. The crust created at Axial is eventually destroyed at the Cascadia subduction zone"	Closure: exit ticket, Under the surface: These students were considering what the inside of the earth would look like if we could see it. Who do you think has the best idea? Explain your thinking. You may draw a picture to show what you think the inside of Earth is like.

Materials and Resources: UNAVCO velocity viewer.
Student supports: In Google Classroom, post exit ticket

> Rudy: I think we would see layers. Most of the inside of Earth will be hot liquid.
> Liz: I think we would see layers. Most of the inside of Earth will be solid.
> Zara: I think we would see three layers with a giant magnet in the center of Earth.
> Mateo: I don't think there are layers. Earth is made up of rocks and dirt with hot liquid found in the cracks.
> Heather: I think we would see sections of solid and liquid Earth with gaps in between.

Student worksheets: Evidence Summary table
Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it

Day 7: Explain

Concept: As heat is released at divergent boundaries, the sea floor spreads apart along both sides of the mid-ocean ridges and new crust is added. This creates symmetry of ocean age on each side of the divergent boundary.
Objective: How do maps of heat flow relate to the location of plate boundaries?

1. Use maps of the ocean floor to identify Mid-Atlantic ridge

<table>
<tr><td colspan="3">2. Create chart diagramming & describing the type of plate motion
3. Discover the relationship between heat flow and plate boundaries
4. Consider evidence from heat flow to Revise model
5. Exit ticket: evaluating evidence</td></tr>
<tr><td>Activities</td><td>Teacher</td><td>Student</td></tr>
<tr><td>Initiate – 10 minutes confirm understandings of types plate boundaries.</td><td>Ask students to create a reference chart of types of plate boundaries</td><td>In s/g, students use dynamic earth interactive to diagram and describe the type of plate motion. Add an example location for each type of motion. Students answer the questions on types of plate boundaries, discuss answers and come to a consensus with their group.</td></tr>
<tr><td>Develop – 25 minutes</td><td>In w/c discussion, review models from last week. Recognize that we are missing a driving force.
Project heat flow map. Ask students to compare the surface heat flow on the continents to the oceans. Ask students to use the map in pairs to answer the questions.
Visit the groups to ask: What happens at divergent plate boundaries? How do you know? Find students to share the concept that “as heat is released at divergent boundaries, the sea floor spreads apart along both sides of the mid-ocean ridges and new crust is added. This creates symmetry of ocean age on each side of the divergent boundary.”</td><td>Use https://eli.lehigh.edu/tectonics/instructional-sequence/investigation-3 to discover the relationship between heat flow and plate boundaries. Students follow Steps 1-2-3.</td></tr>
<tr><td>Closure – 10 minutes. Evaluate evidence</td><td>In w/c discussion, add to evidence Higher temperatures are found at mid-ocean ridges. The seafloor around Axial is hotter than the other areas. Add this concept to “gotta-have it” list</td><td>Exit ticket: Which of the following observations is the strongest evidence for “at mid-ocean ridges, magma rises to form new plate material”? Which is the weakest?</td></tr>
<tr><td colspan="3">Materials and Resources: dynamic earth interactive
Student supports: In Google Classroom, post https://eli.lehigh.edu/tectonics/instructional-sequence/investigation-3 and exit ticket.
Student worksheets: Evidence Summary table
Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it

A. Volcanoes in a line on the bottom of the ocean
B. Shallow earthquakes in a line on the bottom of the ocean
C. Age of seafloor – newer rocks in the middle, older rocks at the edge
D. Topography -- Shallower ocean depths at ridges in the ocean.
E. Heat flow- higher temperatures are found at mid-ocean ridges.</td></tr>
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Day 8: Elaborate

Concept: The earth has a rigid lithosphere above a ductile asthenosphere. Convection currents within the earth's mantle contribute to plate movement

Objectives: What might be happening inside the earth to cause plates to move?

- Demonstrate Inquiry 16.1 convection
- Diagrams and reflection questions

Activities	Teacher	Student
Initiate – 5 minutes	Are we ready to decide that our models are definite, that they include everything that would explain Axial? In reviewing models, recognize that we are missing a driving force or causal mechanism. Ask, how can something made of solid rock move?	Respond with idea that the material under the crust is ductile, and can move more easily than the brittle surface.
Develop – 35 minutes Conduct investigation	Introduce energy as an idea to reason with. Ask how energy works in the atmosphere and in the ocean, could it also work inside the earth? In s/g, conduct Inquiry 16.1 as a verification lab. As students are working, ask questions about how parts of the model connect to the evidence we have accumulated.	Students use jar of convective fluid and a candle to model convection in the mantle. Students make observations of moving fluid and make connections between convection in the mantle and plate motion and landforms. Use worksheet to record ideas.
Closure – 5 minutes Summarize evidence.	Add to evidence list: Convection currents push hot mantle material (plumes) towards the crust, which makes the crust move. Add to "gotta-have it" list. Prepare students to revise models. Ask students "what is puzzling you? What do you think you still need to know?" Ask students to consider the following ideas: are convection currents pushing or are lithospheric plates pulling? Show video up to "we still don't understand"	Students add to evidence list and generate new questions.

Student supports: In Google Classroom, post video
Student worksheets: Evidence Summary table
Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it list

Day 9: Evaluate

Concepts: The mantle's convection cells determine the location of ridges and trenches. Interactions between the rigid lithosphere and the convective mantle cause plate movement, which in turn generates most earthquakes and volcanoes.

Objective: evaluate evidence

- Use MEL to evaluate model (Mid-Atlantic ridge)
- Create symbols for support and contradict (arrows)

Activities	Teacher	Student
Initiate – 5 minutes	Point out connections between convection in the mantle and plate motion and landforms. Tell students it is time to evaluate our models using a tool to help us decide how well our models explain Axial. We're going to zoom in to only look at the	

<table>
<tr><td></td><td>Axial part of our model today, and we'll work on the other parts tomorrow.</td><td></td></tr>
<tr><td>Develop – 35 minutes
Evaluate evidence</td><td>We have gathered a lot of evidence (showing evidence summary table). Now we can use this evidence to help us decide whether our explanations fit with what we now know. Just like detectives use evidence, and reasoning about the evidence, we will as well. I will distribute each piece of evidence on paper, and your job is to compare it to the model to decide whether it supports or contradicts each of the three models.

After 10 minutes, introduce Model-Evidence-Link matrix for evaluating models' fit to the evidence. Project the MEL on the board. Point out that the evidence comes from the evidence summary table. Create shared symbols to represent supports or contradicts. For each piece of evidence, summarize the class consensus about why it.</td><td>On the yellow sticky notes, students write how confident they are with the evidence. Do you think it represents everything we need to know, or could it be false? On the green and blue sticky notes, write why you think this evidence supports or contradicts the model.
Each small group works with one evidence card at a time, and they rotate through the cards, placing the sticky notes as they go. Each student in the group should contribute one note to one of the evidence cards.</td></tr>
<tr><td>Closure – 5 minutes
Evaluate links between model and evidence</td><td>Give each student a MEL to take home and assign homework due Monday: decide which model can be ruled out.</td><td>Students use flipgrid to record themselves explaining which model they would rule out and why.</td></tr>
<tr><td colspan="3">Materials and Resources: evidence cards (video of undersea volcanic eruptions, age of sea floor, subduction zone depth of earthquakes, Iceland's volcanic activity heat flow map, convection in the mantle diagram)
Student supports: In Google Classroom, post video
Student worksheets: Evidence Summary table
Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it list</td></tr>
</table>

<table>
<tr><td colspan="3"><u>Day 10: Evaluate</u></td></tr>
<tr><td colspan="3">Objective:
Present models
Peer review</td></tr>
<tr><th>Activities</th><th>Teacher</th><th>Student</th></tr>
<tr><td>Initiate – 5 minutes</td><td>Tell students, "Now that we have a possible "suspect" for an explanation of Axial, then we have to think about how we would know that it's the best explanation. In other words, how would you know if this is true? Scientists will come up with a testable hypothesis based on their model. For example, you could say "if this explanation is correct, there will be older rock at other trenches on the ocean floor." You might say "If Axial Seamount is formed at a divergent boundary, then we should see the same pattern of newer rock ages at other underwater seamounts." Ask students how we could test the hypothesis.</td><td>Each s/g designs one test for their model.</td></tr>
<tr><td>Develop – 35 minutes
Test models and revise</td><td>After the students clear the test with the teacher they can write their test question on their paper.

Teacher then asks students to evaluate their own models using sticky notes. As a whole class, make a helpful note that adds an idea using a blue sticky</td><td>S/g use the available evidence from the maps or Google Earth or natural hazards viewer to confirm their explanation.
Students create one sticky note per student on their own models.</td></tr>
</table>

<table>
<tr><td></td><td>note - “Put a label on this magma”. Also demonstrate a note that revises an idea using a green note-“we think that this is magma, not water” and question on an orange note “Does your model explain volcanoes on land?” “Does your model show how the Aleutian islands are different from the Axial seamount?”

Project the sentence frames. Point out the “gotta-have it” checklist.

Ask students to revise models to address sticky notes.</td><td>Students visit other groups and add one sticky note to each.

Revise models to address sticky note critique.</td></tr>
<tr><td>Closure – 5 minutes
Confirm model</td><td>Students might conclude that they are “done.” Ask students: could new crust only form at the bottom of the ocean or might it also happen on land? Show PBS video of East African rift
Remind students of homework.</td><td>Students complete their flipgrid homework assignment.</td></tr>
<tr><td colspan="3">Materials and Resources: evidence cards (video of undersea volcanic eruptions, age of sea floor, subduction zone depth of earthquakes, Iceland’s volcanic activity heat flow map, convection in the mantle diagram)
Student supports: In Google Classroom, post video the sentence frames.
Student worksheets: Evidence Summary table
Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it list</td></tr>
</table>

<table>
<tr><td colspan="3"><u>Day 11: Evaluate</u></td></tr>
<tr><td colspan="3">Objective:
1. Students test their models by testing it against secondary data from another location (East Africa)
2. Write final explanation with scaffold</td></tr>
<tr><td></td><td>Teacher</td><td>Student</td></tr>
<tr><td>Initiate – 5 minutes</td><td>Ask students to rule out one of the models on the MEL. Say: “here are four diagrams that could explain what happens over time where two oceanic plates are pulling apart. Which of the following diagrams can you “rule out” as an explanation for sea-floor spreading?”</td><td>Students in s/g discuss which models can be “ruled out.” Which model is the best fit?</td></tr>
<tr><td>Develop – 35 minutes
Construct explanation based on model</td><td>As they work, ask probing questions: How are Aleutian islands different from the Axial seamount? How are the Himalayas different from the Andes? Are there any places where volcanoes don’t fit the patterns we have identified so far?

If students are “done” ask them to extend their thinking with a new location.</td><td>Students use their group model to write an individual explanation of what is occurring at Axial.

Extension: Use your model to explain the landforms and earthquakes you see in East Africa. Do you see any landforms that you could use to make a claim? Do you see deep or shallow earthquakes? What do you think will happen in this region of the world over time? What landforms do you expect to see developing in the future?</td></tr>
<tr><td>Closure – 5 minutes
Critique explanations</td><td>At the end of class, assign new homework. Prompt: This is the work of a student who examined the Axial seamount. How would</td><td>Homework: Use your summary table to respond to an anonymous</td></tr>
</table>

	you respond to this claim? "At mid-ocean ridges, water fills the empty space between two plates?" What evidence would you use to contradict this idea?	student's diagram and explanation (on flipgrid).
Student supports: In Google Classroom, post East Africa mystery. Navigate to the Iris earthquake browser for a view with the following settings: Location: An area from Sudan down through the northern tip of Madagascar View: Satellite (you will need to adjust this) Display: 2000 events Time Range: From 2011-01-01 to latest available Magnitude Range: All Values Depth Range (km): All Values Scaffolds – Claim/Evidence/Reasoning graphic organizer. Student worksheets: Evidence Summary table Public Records: Post Hypotheses List and Evidence Summary Table and Gotta-have-it list		

Assessments
Formative: Evaluating models: "two stars and a wish" critiques (flipgrid) Probing questions (written and oral) Exit slip: Under the surface Exit slip: Which of the following is the strongest evidence? Which is the weakest? Presentation of class models Responses to an anonymous student's explanation (flipgrid)
Multiple Choice: 22 questions
Final Evidence-Based Explanation: Ask students to use their models to write an evidence-based explanation that answers the question: How did Axial come to be located where it is? plate tectonics example explanation & model Rubric Use scaffolds (and exemplars)

Appendix F

Summative Assessment (multiple choice questions)

The assessment includes items modified from the Tectonics Assessment (Copyright 2012 © Environmental Literacy and Inquiry Working Group at Lehigh University.

Learning objective: Tectonic plates move across Earth's surface, carrying the continents, creating and destroying ocean basins, producing earthquakes and volcanoes, and forming mountain ranges and plateaus.

True or False. Write the word "True" or "False" on the line

____1. The youngest ocean floor is located at a transform boundary.

____2. Movement along plate boundaries can produce earthquakes

____3. Plate can carry continents or parts of oceans but not both.

Multiple Choice. Write the letter of the best answer on the line.

____4. The layer of the Earth broken into rigid, slow moving plates is _______

A. Lithosphere
B. Asthenosphere
C. Inner core
D. Mantle

____5. Which term best describes the movement of continents?

A. Rapid
B. Gradual
C. non-existent

____6. The theory that explains how mountains are formed, why earthquakes occur and how the continents have shifted is ________________

A. Plate tectonics
B. Liquefaction
C. Asthenosphere
D. Subduction

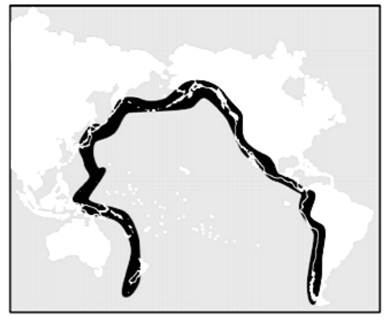
____7. Earthquakes occur near which of the following landforms?

A. Continental coasts
B. Volcanic islands
C. Trenches
D. All of the above

____8. Which is the following is true about volcanoes?

A. Volcanoes occur near plate boundaries.
B. Volcanoes occur only on the subducting plate.
C. Volcanoes occur only near divergent plate boundaries.

____9. What process causes the continents of North America and Eurasia to drift apart?
A. Sea floor spreading
B. Asthenosphere
C. Magnetic field



____10. Earthquakes and volcanic activity occur along the Pacific Ring of Fire. Which of the following best explains why?
A. It is located in the center of a tectonic plate
B. It is located at the boundaries of tectonic plates
C. It is located where the major ocean currents meet
D. It is located where ocean temperature is the highest

____11. At a mid-ocean ridge, what causes the underwater mountain range to form?
A. molten material from several kilometers below the surface.
B. exploding hot rock from the core
C. drifting rock from South America.

____12. At convergent boundaries, one plate is sometimes subducted below another. What is the best definition of “subduction?”
A. moving from side to side
B. pulling apart
C. sliding or sinking under

____13. What is the underlying process that drives plate motion?
A. Ocean tides
B. Volcanic eruptions
C. The rock cycle
D. Convection currents

____14. In Figure 1, which has formed at location A?
A. an ocean trench
B. a mid-ocean ridge
C. a volcanic island chain
D. a coral reef island

____15. In Figure 1, which has formed at location B? a
A. An ocean trench
B. a mid-ocean ridge
C. a volcanic island chain
D. a coral reef island

____16. In Figure 2, where is the oldest ocean floor located?
A. Location A.
B. Location B.
C. Location C.

D. Location E

____17. Figure 2 can be used to support (<u>choose 2</u>)

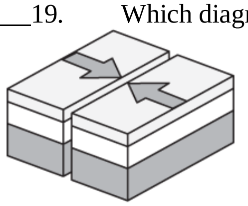
A. sea floor spreading.
B. subduction of an oceanic plate.
C. formation of new oceanic crust.
D. formation of a volcanic island chain.

____18. Which of the following is TRUE about boundaries between Earth's plates?

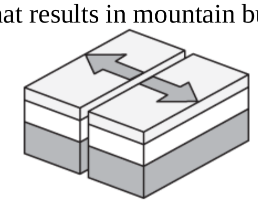
A. Boundaries are never found in continents.
B. Boundaries are always located in the middle of ocean basins.
C. Boundaries are always located where ocean basins meet continents.
D. Boundaries can be located anywhere in an ocean basin or in continents.

____19. Which diagram best represents the type of plate movement that results in mountain building?

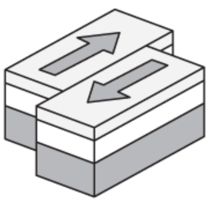
A.



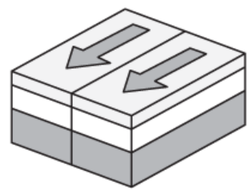
C.



B.

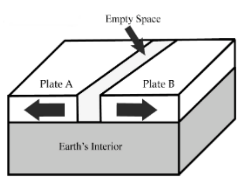


D.

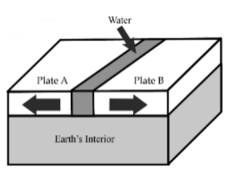


____20. Each of the diagrams below show a plate boundary where two oceanic plates are pulling apart. Which of the following happens over time as the plates pull apart?

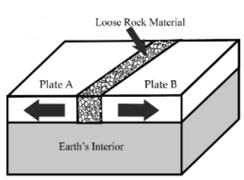
A. An empty space forms between them that gets wider over time



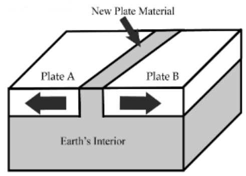
B. Water immediately fills the empty space between them



C. Loose rock material immediately fills the empty space between them



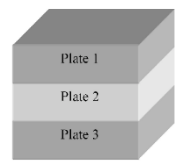
D. Magma rises to form new plate material, so there is no empty space



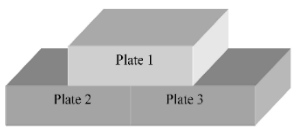
____21. Which of the following represents how three of Earth's plates fit together?

A.

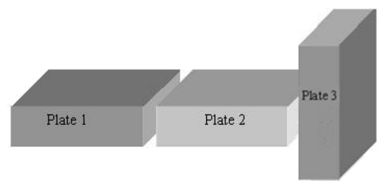
C.



B.



D.



____22. How is a transform boundary different from a convergent boundary?

A. Plates move apart at transform boundaries, and towards each other at convergent boundaries.
B. Plates move underneath each other at transform boundaries and over one another at convergent boundaries
C. Plates move toward each other at convergent, and side-to-side at transform boundaries.
D. Continental drift does not occur along convergent boundaries; it does occur at transform boundaries.