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Discussion in Middle and High School Earth Science Classrooms and Its Impact on Students' Abilities to Construct Evidence-Based Arguments in Their Written Work

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DISCUSSION IN MIDDLE AND HIGH SCHOOL EARTH SCIENCE CLASSROOMS AND ITS IMPACT ON STUDENTS' ABILITIES TO CONSTRUCT EVIDENCE-BASED ARGUMENTS IN THEIR WRITTEN WORK

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THESIS ACCEPTANCE STATEMENT

On behalf of the Graduate Committee for Rachel A. Martin, I affirm that this manuscript is the final and accepted thesis. Signatures of all committee members are on file with the Graduate School at the University of Maine, 42 Stodder Hall, Orono, Maine.

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Thesis Advisor: Dr. Susan McKay

An Abstract of the Thesis Presented
In Partial Fulfillment of the Requirements for the
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Middle and high school teachers who participate in the Maine Physical Sciences Partnership (MainePSP) noted persistent problems in their classrooms, including low levels of student engagement and gaps in how students use evidence. To address these problems, this study was designed in collaboration with MainePSP teachers in a design-based implementation research process as teachers aimed to better connect classroom discussion and written argumentation. Though scientific writing makes use of argumentation to support ideas, it is often the sharing of ideas that makes an argument stronger.

Two teachers collected data from their seventh and ninth grade Earth Science classrooms at schools in central Maine. Written responses were collected as students answered two questions from their respective curricula. For the first question, students provided their answers without discussing the question beforehand. This question provided a baseline of ability to measure gains made on the second question. For the

second question, classrooms were assigned to one of three discussion protocols—no discussion, discussion without Talk Science, and discussion with Talk Science. Talk Science is a discussion method designed to facilitate productive classroom discussion by emphasizing evidence and reasoning.

For both questions, students were instructed to write their answer using the Claim, Evidence, Reasoning (CER) framework that was already being used in both of the participating classrooms. This style of argumentation allows the students to make a claim and support it using two pieces of evidence. Then, reasoning is used to connect the evidence to the claim. The written responses were analyzed using a project-specific CER and Content rubric that was also designed in collaboration with high school teachers.

Analyses suggest ninth graders improve their scores on evidence, reasoning, and content when encouraged to have a Talk Science discussion. These gains are most likely due to the emphasis that Talk Science places on sharing evidence and reasoning, which supports content knowledge. Seventh graders showed the most improvement on their claim when encouraged to have a Talk Science discussion. Audio data from the discussions reveal some factors responsible for this difference. While, the ninth grade teacher prompted students to support their statements by sharing evidence and reasoning, the seventh grade teacher focused prompted students to ‘add on’ to others’ statements.

In addition, all of the students were asked to reflect on their classroom discussion and the results were strongly positive. Most students valued the discussions either for obtaining information directly related to answering the question or for gaining further explanation of ideas taught in class.

The results of this study will be used to influence classroom instruction and professional development within the MainePSP. Because the use of CER and content knowledge were shown to improve, other teachers may be more likely to include discussions with Talk Science and written CER argumentation in their classrooms. Furthermore, though teachers often report that classroom discussions take too much time or do not seem to engage students, it is apparent here that students do value classroom discussion.

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LIST OF ABBREVIATIONS

CER	Claim, Evidence, Reasoning framework
DBIR	Design-based implementation research
GCCIR	MainePSP Global Climate Change Instructional Resources
MaineESP	Maine Elementary Sciences Partnership
MainePSP	Maine Physical Sciences Partnership
MST	Master of Science in Teaching
RiSE Center	Center for Research in STEM Education
SEPUP	Science Education for Public Understanding Project
TAP	Toulmin's Argument Pattern framework

CHAPTER 1

INTRODUCTION

In 2013, teachers of the Maine Physical Sciences Partnership (MainePSP) working with the University of Maine's Center for Research in STEM Education (RiSE Center), identified two problems encountered in their classrooms: 1) lack of deeper student engagement and 2) students' poor use of evidence. The second problem is closely related to argumentation, which is also a process for addressing the first problem. To address these areas, teachers sought to incorporate active discussion, which has been found to require student engagement (Duschl et al., 2007) and can incorporate evidence-based argumentation (Shemwell & Furtak, 2010). This study explores the impact of classroom discussion, particularly productive talk discussion, on students' written argumentation, including their use of evidence.

Design-Based Implementation Research

Within the MainePSP, researchers and teachers collaborated in a design-based implementation research (DBIR) process to study discussion and argumentation. Design-based implementation research requires that teachers and researchers work together to better address the needs of both parties (Penuel et al., 2011). Researchers have demonstrated that teacher involvement in the design process greatly increases the likelihood of successful implementation in the classroom (Penuel et al., 2011). Penuel et al. (2011) designed DBIR to be applicable in multiple contexts, including across subjects and administrative scales. However, the researchers state that everyone involved must be "ready for change" for the process to be successful (Penuel et al., 2011, p. 334).

Scientific Argumentation

Scientific argumentation is present in a number of national standards, including *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993), *National Science Education Standards* (National Research Council, 1996), and *Next Generation Science Standards* (NGSS Lead States, 2013). *Inquiry and the National Science Education Standards* (National Research Council, 2000), an additional report from the National Research Council, identified five characteristics of classroom inquiry, of which four are closely related to argumentation (McNeill & Krajcik, 2012). To enhance public understanding of science and, thus, to improve scientific literacy, schools must prioritize argumentation and the associated skills (Driver et al., 2000). Unfortunately, argumentation is difficult for many people and, often, that is because it is not taught well in classrooms (Reznitskaya et al., 2001).

Osborne et al. (2004) demonstrated that the use of language and scientific methods made students more scientifically literate. Importantly, students' written arguments have been shown to be stronger when they are encouraged to have discussions using argumentation (McNeill, 2011). Moreover, scientific writing has been shown to increase retention and increase conceptual learning (Rivard & Straw, 2000; Hand et al., 2004).

Students are more likely to express their ideas and share their thinking in writing than during classroom discussion (Furtak & Ruiz-Primo, 2008). However, research has shown that the ability to communicate through talking typically precedes students' abilities to communicate through writing (Berland & McNeill, 2010). Though Knight and McNeill (2012) claimed the opposite was true in their study, they offer a number of reasons to explain why students' written arguments were more sophisticated than their oral arguments. Furthermore, Berland and McNeill (2010) found that students' abilities may not be truly represented by their written work and, additionally, written assignments may not push students' thinking.

Discussions in Classroom Learning

Newton et al. (1999) discussed the sociolinguistic aspect of learning one's community norms. This requires that students, as well as nonstudents, participate in both talking and writing (Driver et al., 1994). Schools have been recommended as the best place to learn how to participate in discussion because of the variety of subjects and types of discussion present (Resnick et al., 2010). Recently, science education has expanded the focus to learning community practices in addition to problem solving, concept learning, and science process skills (Erduran et al., 2004).

Newton et al. (1999) suggest that a social constructivist approach should be taken when discussing science education. This theory supports including more discussion and group work (Newton et al., 1999), which is consistent with Vygotsky's (1978) work on social learning. The discussion framework used in this study, Accountable Talk, was developed from a Vygotskian perspective to encourage student interaction (Michaels et al., 2008; Resnick et al., 2010).

In a classroom setting, collaborative reasoning discussions have been shown to increase students' use of appropriate arguments, counter-arguments, rebuttals, formal argument devices, and text information in a way that leads to a deeper learning about the role of argumentation (Reznitskaya et al., 2001). Furthermore, Kuhn et al. (1997) used a number of case studies to demonstrate that repeated discussion increases the quality of reasoning about a topic. The sharing of ideas has been shown to "[improve] the quality of the student experience, the depth of student thinking, and their learning of science itself." (Osborne, 2010, p. 466). There is also evidence that, with proper training, students can internalize these collaborative skills and transfer them from the classroom to civic life (Erduran & Jiménez-Aleixandre, 2008; Michaels et al., 2008).

Research Frameworks

Argumentation

Argumentation is a process of building arguments that provides students with the opportunity to participate in a standard scientific practice (Berland & McNeill, 2010; Driver et al., 2000). Science, as a discipline, typically progresses through resolved disagreements rather than initial agreement; thus, it is necessary that students learn skills in argumentation (Erduran et al., 2004). Duschl and Osborne (2002, p. 41) described argumentation as "the process of constructing an argument" and an argument as "a referent to the content of argument," while McNeill et al. (2006, p.158) defined argumentation as a "scientific explanation."

Though argumentation is not the only form of scientific communication, it is recommended that argumentation be prominent in science classrooms because it plays a central role in the science community (Berland & McNeill, 2010; Duschl & Osborne, 2002). Yet, although argumentation is critical to science, often it is not included in science education (Newton et al., 1999; Osborne, 2010). Argumentation is a concept that is best learned when taught over an extended period of time because most people struggle with forming arguments and need practice to improve (Berland & McNeill, 2010; Kuhn, 1991; Osborne et al., 2004). A number of frameworks have been developed to guide argumentation, but most are built upon Toulmin's Argument Pattern.

Toulmin's Argument Pattern. Toulmin's Argument Pattern (TAP) consists of five parts: claims, data, warrants, backings, and rebuttals (Toulmin, 1958; Erduran et al., 2004; Fig. 1).

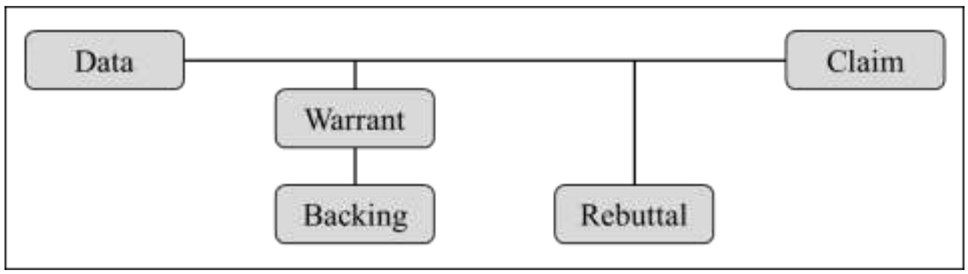


Figure 1. Toulmin's Argument Pattern of claims, data, warrants, backings, and rebuttals. Adapted from Erduran et al. (2004).

Toulmin ignored the truth-seeking aspects of an argument and emphasized the components that make a strong argument, such as warrants and backings (Duschl & Osborne, 2002). TAP has been used to analyze student work in a wide range of subjects and has been used as both a formative and summative assessment (Erduran et al., 2004). It has been primarily researched in small group discussions during science lessons, but this research has encountered difficulties (Erduran et al., 2004). For instance, researchers often have a hard time differentiating the parts of a TAP argument (Erduran et al., 2004).

Moreover, the TAP framework is often difficult for scientists to interpret (van Eemeren et al., 1996) and for middle schoolers to follow (McNeill et al., 2006). Thus, a number of additional frameworks have been put forth, but often are built upon Toulmin's

Argument Pattern. The study presented here is most interested in the Claim, Evidence, Reasoning framework presented by McNeill et al. (2006).

Claim, Evidence, Reasoning. McNeill et al. (2006, p.158; Fig. 2) define argumentation, or "scientific explanation," as being composed of three parts: 1) claim—"an assertion or conclusion that answers the original question;" 2) evidence—"scientific data that supports the claim;" and 3) reasoning—"a justification that shows why the data count as evidence to support the claim." A fourth component, the rebuttal, is considered a more advanced piece of argumentation. The rebuttal should be added after mastery of claim, evidence, and reasoning (McNeill & Krajcik, 2012), so, for that reason, it is not considered in this study.

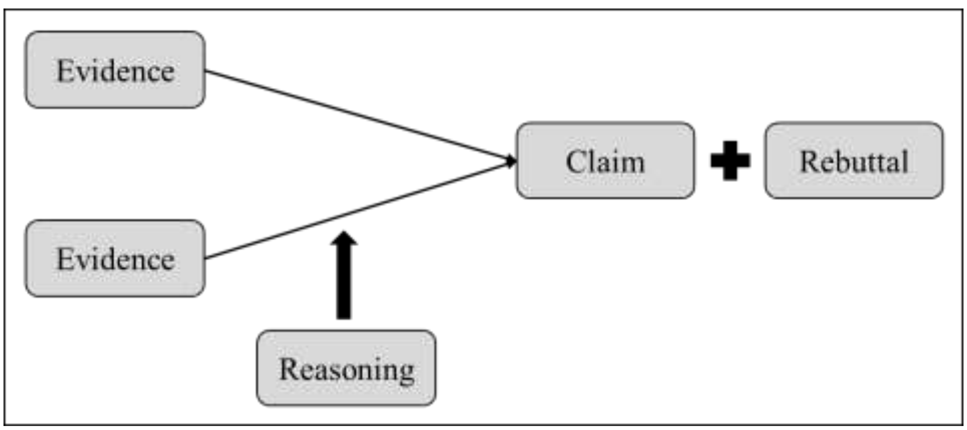


Figure 2. Claim, Evidence, Reasoning framework of claim, evidence, reasoning, and rebuttal. Adapted from McNeill and Krajcik (2012).

The Claim, Evidence, Reasoning (CER) framework was developed with consideration for national guidelines and to be a more accessible version of Toulmin's Argument Pattern (McNeill & Krajcik, 2012), such that the claim is equivalent to TAP's claim, the evidence is equivalent to TAP's data, and the reasoning comprises TAP's warrant and backing. For students first developing skills in argumentation, an ideal argument consists of a claim, two pieces of evidence, and reasoning and these parts may be present within the same sentence or they may be distributed throughout a piece of writing (McNeill et al., 2006). The claim is expected first because it is meant as the answer to a question while the evidence and reasoning provide the support (McNeill & Krajcik, 2012).

Though research on students' understanding of argumentation is fairly new, it is known that students must be instructed on the proper language (claim, evidence, and reasoning) before they can be expected to construct their own argument (Osborne, 2010). The claim is believed to be the easiest part of the argument for students (McNeill & Krajcik, 2012), but Sadler (2004) demonstrated that students can struggle with both articulating and defending claims. When asked to write a complete CER argument, students are most challenged by the reasoning aspect (McNeill et al., 2006; McNeill & Krajcik, 2012).

Discussion

In a science classroom, discussion should play a critical role in the learning of scientific knowledge and practices (Knight & McNeill, 2012) because there is the potential benefit of immediate feedback from a teacher or peers (Pimentel & McNeill, 2013). Based on current literature, Pimentel and McNeill (2013) provide three reasons for improving science discussion: 1) increasing content understanding; 2) teaching scientific practices; and 3) changing perceptions of science. Despite this, discussions are not a frequent occurrence in science classrooms (Newton, et al., 1999).

Teachers often have little to no experience with scientific communication (Duschl & Osborne, 2002; Newton et al., 1999) and often lack the pedagogical skills and confidence to successfully manage classroom discussions (Newton et al., 1999; Driver et al., 2000). Therefore, though teachers often recognize that better discussions will increase learning, they find it challenging to shift away from more traditional methods of instruction, such as call-and-response (Knight & McNeill, 2012; Pimentel & McNeill, 2013; Osborne et al., 2004; Newton et al., 1999).

Teachers provide three primary reasons for not using whole class discussions: 1) students' lack of knowledge, experience, and/or motivation; 2) lack of ability to engage a classroom of students; and 3) time constraints to cover all content (Pimentel & McNeill, 2013). This avoidance of whole class discussions only perpetuates the problems because students need to be provided with practice time to develop their skills and increase their engagement and content knowledge (Duschl et al., 2007).

Group discussions have been shown to increase learning if students are provided with the proper support, such as norms of social interactions, exemplars, defined outcomes, and informative materials (Osborne, 2010). Younger grades need progressively more support than the older grades (McNeill, 2011). While elementary students find it difficult to just make a claim, middle school students are able to make a claim, but require more support to justify those claims (McNeill, 2011). Though these supports are necessary, it has been shown that fading scaffolding is more productive than continuous scaffolding (McNeill et al., 2006). Discussion can provide this scaffolding by encouraging students to share their ideas. The study presented here is most interested in the impact that Talk Science discussions have on written work in comparison to no discussion or a more traditional, call-and-response type of discussion.

<u>Traditional Discussion.</u> In this study, “traditional discussion” resembles a call-and-response style of classroom management. This is a teacher-centered classroom that does not encourage students to develop reasoning skills by doing science, but is usually focused on recall rather than evaluation and synthesis (Duschl & Osborne, 2002). In this common situation, the students respond with short statements and do not include justifications or collaborate with their peers (McNeill & Krajcik, 2012; Pimentel & McNeill, 2013). Because of the prevalence of call-and-response instruction, students are given the impression that science consists of completely agreed upon facts that are unchanging (Newton et al., 1999).

<u>Talk Science.</u> The method of discussion that is of interest in this study, Talk Science, was designed by researchers at TERC, an education research institution, to stimulate productive talk in the classroom using Accountable Talk as a framework (Michaels et al., 2008; Resnick et al., 2010). Accountable Talk was developed from a Vygotskian approach that emphasizes “the importance of social interaction in the development of individual mental processes” (Michaels et al., 2008, p. 285). In an Accountable Talk discussion, participants are held accountable to their learning community, the standards of reasoning, and knowledge (Michaels et al., 2008; Resnick et al., 2010). Resnick et al. (2010) presented six talk moves to encourage an Accountable Talk discussion.

Building upon Accountable Talk, Talk Science adds three more talk moves for a total of nine talk move that address four goals of a productive discussion: 1) “share, expand, and clarify their own thoughts;” 2) “listen carefully to one another;” 3) “deepen their reasoning;" and 4) "think with others" (Michaels & O'Connor, 2012, p. 9). Talk Science is designed to emphasize evidence and reasoning, which may require the consideration of incorrect or incomplete ideas (Michaels et al., 2008) and can be difficult for teachers (Pimentel & McNeill, 2013). At the start of this project, Talk Science had been successfully implemented in the Maine Elementary Sciences Partnership (MaineESP) K-5 classrooms and was just being introduced in MainePSP 6-9 classrooms.

As with any type of productive talk, Talk Science can be challenging to implement in a classroom because the norms of discussion, such as listening attentively and responding respectfully, are differentially available to students in their lives outside of school (Michaels et al., 2008). The students for whom discussion norms are readily available may be more fluent in this manner of discourse, which may create an unbalanced discussion dominated by a few students (Michaels et al., 2008).

When a classroom uses Talk Science, it is characteristic of Duschl and Osborne's (2002) classroom focused on evaluation and synthesis rather than recall. This classroom is typically more student-centered and includes more peer discussion (Duschl & Osborne, 2002). Often, teachers pose open-ended questions and allow their students to interact as they share ideas (McNeill & Krajcik, 2012). This discussion style has been shown to increase academic achievement for diverse groups of students (Michaels et al., 2008).

Instructional Resources

In 2010, the RiSE Center established the MainePSP to partner with middle and high school teachers across the state of Maine to improve science education as a community. The MainePSP teachers share instructional resources for sixth, eighth, and ninth grade science. This research was completed in classrooms using two of these shared sets of instructional resources.

MainePSP Global Climate Change Instructional Resources

Ninth grade classrooms use the MainePSP Global Climate Change Instructional Resources (GCCIR), which was adapted from the EarthComm: Project-Based Space and Earth System Science program developed through a collaborative process led by the American Geological Institute (Benbow et al., 2012). Over the course of one school year, students in the MainePSP learn from five modules, including Astronomy; Earth Systems Evolution; Plate Tectonics; Winds, Oceans, Weather and Climate; and Natural Resources and Climate Change (Maine Physical Sciences Partnership, n.d.). Each module is divided into a number of sections. Ninth grade teachers developed GeoLogs, or worksheet packets, that correspond with each section. The GCCIR are designed to use guided inquiry learning in a way that is meaningful to students.

SEPUP Instructional Resources

Within the MainePSP, sixth and seventh grade classrooms use the Issues & Earth Science program from the Science Education for Public Understanding Project (SEPUP) of the Lawrence Hall of Science, University of California Berkeley (Regents of the University of California, 2012; Maine Physical Sciences Partnership, n.d.). Lessons, called activities by SEPUP, are clustered into seven units, including Studying Soils Scientifically, Rocks and Minerals, Erosion and Deposition, Plate Tectonics, Weather and Atmosphere, The Earth in Space, and Exploring Space. SEPUP is designed to provide guided inquiry learning and includes relevant social issues, such as urban development and nuclear waste storage.

Establishing Norms

Within any curriculum, successful implementation of new instructional methods requires the construction of a classroom culture that includes scientific argumentation, patterns of teacher and student talk, and certain types of teacher questions, such as open-ended ones (McNeill & Krajcik, 2012). Importantly, students must be allowed time to practice scientific skills, including argumentation, if they are to be expected to master those skills and, as such, these skills must be established as norms in the classroom (Driver et al., 2000; McNeill & Krajcik, 2012). Students must be taught how to participate in scientific discourse (Lemke, 1990). At the same time, students must be taught how not to behave when participating in a discussion (Duschl & Osborne, 2002).

It is critical that teachers establish norms in their classrooms to provide expectations, as well as examples, for students to use as guidelines (McNeill, 2009; McNeill & Krajcik, 2012). Teachers' behaviors, both positive and negative, directly influence students' engagement in classroom discussion; however, teachers may not realize the constraints that these behaviors place on students (Pimentel & McNeill, 2013; Simon et al., 2006). Teachers should advance through a process that includes "focus[ing] on the importance of talking and listening to others, conveying the meaning of argument through modelling and exemplification, positioning oneself within an argument and justifying that position using evidence, constructing and evaluating arguments, exercising counter-argument and debate, and reflecting upon the nature of argumentation" (Simon et al., 2006, p. 255).

Study Goals

Research Questions

The MainePSP teachers were concerned about student engagement and students' ability to work with evidence. Additionally, Erduran et al. (2004) suggested that future work investigate how student engagement in classroom argumentation improves their learning. Thus, the study presented here is primarily interested in determining if, how much, and in what ways discussion impacts students' written arguments. Specifically, how does a productive talk discussion, such as Talk Science, influence students' construction of an argument using a structure, such as the Claim, Evidence, Reasoning framework?

Impacts

The results of this study can potentially be used to influence classroom instruction and teacher professional development within and outside of the MainePSP. It has been documented that few teachers will implement new methods in their classrooms without evidence of a positive outcome (Duschl & Osborne, 2002; Newton et al., 1999). In addition, teaching methods greatly influence students' abilities to reason (Erduran et al., 2004) and there is evidence that properly used talk-based pedagogy is likely the best option for successful classroom instruction (Resnick et al., 2010). Therefore, teachers must be prepared and provided with support (Newton et al., 1999) if students are expected to learn the language of discourse and successfully participate in both discussing and writing about science (Driver et al., 1994).

CHAPTER 2

METHODS

Data were collected from one high school classroom and two middle school classrooms during the fall of 2015. In each study iteration, students were asked to provide written answers to two questions, which will be referred to as Questions 1 and 2, following normal classroom instruction. Question 1 was answered without discussion beforehand. Prior to answering Question 2, classrooms were assigned to one of three discussion protocols. The written answers were scored by three people using a study-specific rubric and analyzed to determine the impact made by the three discussion protocols.

Participants

Each participating teacher was involved with the MainePSP through the Maine RiSE Center. Each teacher who participated in data collection was required to have at least three sections of the same course. All of the students in this study were enrolled in an Earth Science class in a public school, either middle school or high school, in Maine. Graduate students who assisted with data analysis were enrolled in the Master of Science in Teaching (MST) program through the RiSE Center.

High School

Data were collected from one high school teacher's Earth Science classes in this iteration of the study. A total of 33 ninth grade students provided at least one written response. Twenty-seven students answered Question 1, and 28 students answered Question 2; however, only 22 students answered both questions and, thus, produced paired data. When discussing the high school data, the teacher will be referred to by a pseudonym, Ms. Allen.

Middle School

Data were collected from two middle school teachers' Earth Science classes in this iteration of the study. In all, 71 sixth graders and 62 seventh graders provided written responses. Because of an error with data collection in the sixth grade classroom, the sixth grade data will not be included in the analyses. Of the 62 seventh graders, 52 answered Question 1 and 58 answered Question 2; however, only 48 students answered both questions and, thus, produced paired data. When discussing the middle school data, the seventh grade teacher will be referred to by a pseudonym, Ms. Johnson.

Questions

High School

The ninth grade teacher was active in the MainePSP and was actively using the MainePSP GCCIR curriculum. For this research, two questions were chosen from the 'Think About It Again' questions provided at the end of each GeoLog for Module 1: Astronomy (Table 1). Question 1 came from GeoLog 1.1-3: "What do the movements of stars and galaxies tell astronomers about how the universe formed?" (Appendix A). Question 2 came from GeoLog 1.7: "How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?" (Appendix B). Students were provided answer sheets with instructions for writing with the CER framework (Appendix C).

Middle School

The seventh grade teacher was active in the MainePSP and was using the SEPUP Issues & Earth Science program. Questions for the seventh grade study were selected from the 'Analysis' sections within Unit C: Erosion and Deposition of this set of instructional resources (Table 1). Question 1 came from Activity 26: Boomtown's Topography: "Do the maps indicate possible problems for building at any of the possible locations—Delta Marsh, Green Hill, and Seaside Cliff?" (Appendix D). Question 2 came from Activity 29: Weathering, Erosion, and Deposition: "At which of the three building sites—Delta Marsh, Green Hill, and Seaside Cliff—would you expect erosion and deposition to have the most effect on the land?" (Appendix E). Students were provided answer sheets with instructions for writing with the CER framework (Appendix F).

Table 1. Study questions selected for high school and middle school students.

Study	Identifier	Question
High School	1	What do the movements of stars and galaxies tell astronomers about how the universe formed?
	2	How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?
	Prompt	What is electromagnetic radiation and how is it used by scientists?
Middle School	1	Do the maps indicate possible problems for building at any of the possible locations—Delta Marsh, Green Hill, and Seaside Cliff?
	2	At which of the three building sites—Delta Marsh, Green Hill, and Seaside Cliff—would you expect erosion and deposition to have the most effect on the land?
	Prompt	How do erosion and deposition affect the landscape?

Implementation of Discussion

Participants answered the first questions (Question 1) without any preceding discussions ('No Discussion'). This established a baseline of the students' abilities to form written arguments. Three whole-class discussion protocols were implemented for the second questions (Question 2) and each teacher was allowed to select which of their three classes (differentiated as A, B, and C) followed each of the three protocols. Classes were assigned to 'No Discussion,' 'Discussion without Talk Science,' and 'Discussion with Talk Science' (Table 2). The classes that used Talk Science were provided with a handout that was adapted from the Talk Science Checklist (Appendix G). In the high school classroom, a MainePSP Teaching Partner was present and served as an assistant in the class that had the discussion with Talk Science; however, he did not play a large role in the discussion and spoke minimally.

Table 2. Discussion protocol assignments for each class. All three classes (A, B, and C) belong to the same teacher. The same protocol design was used for both high school and middle school.

		Question 1	Question 2
Class	A	No Discussion	No Discussion
	B	No Discussion	Discussion without Talk Science
	C	No Discussion	Discussion with Talk Science

When asked to discuss, students in Classes B and C did not discuss Question 2, but were prompted with a related question written by teachers and researchers to elicit rich discussions. For high school students, Question 2 was prompted with: "What is electromagnetic radiation and how is it used by scientists?" and, for middle school students, Question 2 was prompted with: "How do erosion and deposition affect the landscape?" Because a related prompt question was used, students were forced to draw upon their discussion and think critically about the question they answered in writing rather than simply writing what was discussed previously.

Data Collected

Three forms of data were collected: 1) rubric scores for students' written responses; 2) students' discussion reflections; and 3) audio recordings of classroom discussions.

Rubric Scores

A scoring rubric was designed to standardize the scoring of students' responses using the CER rubric provided by McNeill and Krajcik (2012) as a template. Many drafts of the rubric were prepared over the course of the study and they were routinely edited by RiSE Center staff, MST students, and MainePSP teachers. In the end, the rubric included four scores (1-4) for four categories: 1) quality of claim; 2) use of evidence; 3) quality of reasoning; and 4) accuracy of content (Fig. 3). The first three encompass the CER framework. A score for content allowed for the separation of student learning and student ability to construct a written argument using CER, although these are closely connected for many students.

	1 Does Not Meet Expectations	2 Partially Meets Expectations	3 Meets Expectations	4 Exceeds Expectations
Content	Does not make a claim or claim is unrelated to the question	Claim restates the question, provides no new information, or provides incorrect information	Claim answers the question and is correct, but does not stand alone	Claim answers the question, is correct, and stands alone; includes a qualitative or quantitative context
Evidence	Does not provide evidence or evidence does not support the claim	1 piece of evidence or fact that supports the claim, but no data is provided	2 pieces of evidence or facts that support the claim and may include 1 piece of data	2 pieces of evidence or facts that support the claim and includes data
Reasoning	Does not provide reasoning or reasoning is unrelated to question, claim, or evidence	Refers to the claim and evidence, but is missing details or scientific principles or may restate claim	Links the claim and evidence using scientific principles	Links the claim and evidence using scientific principles and provides a deeper understanding and/or addresses greater impacts
Content	Does not demonstrate an understanding of the lesson and may include false or irrelevant information	Demonstrates a general understanding of the lesson, but does not incorporate specific data or facts	Demonstrates a good understanding of the lesson and incorporates some data or facts, but is missing relationships	Demonstrates a strong understanding of lesson and incorporates specific data and facts to construct relationships

Figure 3. Rubric designed for this research to score students' written responses. Adapted from McNeill and Krajcik (2012).

All scoring of student responses was done using a blind method, so that scorers did not know which students had which discussion protocols. Student responses were scored by the author and two other MST students from the RiSE Center to ensure inter-rater reliability. Because of the complexity of the responses, it was necessary for each of the three scorers to score each response. The scores were discussed until a consensus was reached. With both the high school and the middle school data, the three scorers reached 100% agreement. For scoring purposes, some assumptions had to be made:

- The first sentence was accepted as the claim; though, exceptions were allowed if all scorers agreed. Only one exception was made for a seventh grade response where the last sentence was clearly written as a claim. This exception was agreed upon by the three scorers.
- Based on discussions with ninth grade teachers, the word ‘data’ does not refer to the same thing as the word ‘evidence.’ In their classrooms, evidence is any and all support of a claim, while data are quantitative measurements. Therefore, all data could be used as evidence, but not all evidence could be data.
- It is impossible to have reasoning without including evidence. Thus, any responses that did not include satisfactory evidence could not be given a high reasoning score.
- Responses written as lists, either with bullet points or numbers, were not included because argumentation involves using language to connect ideas and a list does not accomplish this. Eight middle school students were excluded from the study because of this, which brought the number of paired responses to 40. However,

responses that made use of headings to indicate the parts of their argument (i.e. claim, evidence, and reasoning) were included.

- Mathematical symbols and drawings were not accepted as written work because, as with lists, symbols and drawings do not clearly convey the language necessary for argumentation. However, arrows indicating increasing, decreasing, or movement were accepted because many teachers reported using arrows in this way during instruction.

Only students who answered both questions were included in the analysis. The distribution of scores was considered independently for each of the four parts of the rubric. A gains score was determined for each of the four parts of the rubric. For each, the score for Question 1 was subtracted from the score for Question 2 to produce a quantifiable gain. Gains were categorized as ‘positive,’ ‘neutral,’ or ‘negative’ to account for the categorical scoring procedure. Within each rubric part, gains scores were sorted into their original discussion protocol groupings to better demonstrate which class made the most improvement between Question 1 and Question 2.

Discussion Reflections

Following the second questions, students were asked to reflect on the usefulness of discussion. Students who did not have a discussion were asked “How would a discussion have helped you write your answer?” (Appendix H) and students who did have a discussion, either with or without Talk Science, were asked “How did your discussion help you write your answer?” (Appendix H).

The reflections were divided into four categories: 1) not reflective; 2) negative; 3) positive, appreciates answer; and 4) positive, appreciates explanation (Fig. 4). Though the latter two categories were both positive, the reflections can be easily divided. The third category included students who valued gaining information that could be used to write an answer. The fourth category included students who valued gaining a better understanding of the material, which then helped them write an answer. Some reflections provided content examples and those were given an asterisk (*) after the numerical score. Reflections that only included content were scored as ‘not reflective,’ but were asterisked for providing an example.

For scoring purposes, the scores were considered additive, so that, when a student emphasized ideas from two or more categories, the higher score was assigned. Discussion reflections were also scored by the author and the same two MST students who assisted with the rubric scoring of the written responses. The scores were discussed until a consensus was reached. With both the high school data and the middle school data, the three scorers reached 100% agreement.

Score	Definition		Example
1	Not reflective	Provides unclear information about the usefulness of a discussion.	*Because our whole class discussed it and we recorded it so you can look back at the recording.*
2	Negative	Does not value a discussion when writing a response.	*people are dumb so it didnt help me. It was just a distracton and a waste of time.*
3	Positive, appreciates answer	Values a discussion and appreciates more information to use.	*I heard a lot of opinions to write down. Most were the same, giving me the correct answer.*
4	Positive, appreciates explanation	Values a discussion and appreciates greater understanding of content.	*(It) helped me understand things more. When everyone was involved. It also helped explain things easier.*
*	Provides an example	Provides content from the discussion, may score 1-4 above.	*We talked about the doppler effect and how the universe is expanding.*

Figure 4. Rubric for scoring discussion reflections with definitions and examples. Students who provided a content example have an asterisk (*) after their numerical score of 1-4. Examples from high school students are indicated with italics.

Audio Recording

Each discussion was audio-recorded using either handheld recorders or cell phones. Each discussion was recorded by multiple devices to ensure adequate coverage. The discussions were transcribed using Express Scribe Transcription Software (NCH Software, 2016). Classroom discussions centered on classroom management were deleted from the transcription, though the breaks were indicated. Pseudonyms were provided for the teachers and a number was provided for each student. When a student could be identified as a previous speaker, his or her number was maintained. However, often this distinction was not possible; thus, in many cases multiple numbers might refer to the same student. Transcription codes are provided in Table 3.

Table 3. Codes used in transcriptions of audio recordings.

Code	Definition
///	Indicates that the speaker trailed off without completing his or her thought.
/	Indicates that the speech was truncated, usually because the speaker was interrupted.
(…)	Indicates that a section of speech is either inaudible or unintelligible.
…	Indicates a pause in speech.

The transcriptions were analyzed for frequency of teacher statements that included talk moves and frequency of student-student discussion. Frequency of talk moves was determined by calculating a percentage by counting the number of moves and the total number of times the teacher spoke. Student-student discussion was defined as an interaction between students that contributed positively to the discussion. This did not include off-task comments (e.g. “I thought we had one quiz.”) or agreeing/disagreeing comments (e.g. “That’s what I was going to say.”).

Teacher Perspective

Following data collection, the participating teachers were sent a brief questionnaire to gain their perspectives on the research project (Appendix I). This questionnaire consisted of eight open-ended questions that were written by the research team. This was emailed with a copy of the scoring rubric and both teachers responded with their feedback.

CHAPTER 3

RESULTS

Three types of data were collected in this study: 1) written responses to questions; 2) written reflections about the discussion; and 3) audio recordings of the discussion. The results of each are reported from the high school classroom and then middle school classroom.

Rubric Scores

High School

In the high school section of this study, 22 students answered both questions and their scores are reported here. The ‘No Discussion’ class had four students, the ‘Discussion without Talk Science’ class had seven students, and the ‘Discussion with Talk Science’ class had 11 students. Because of the small number of students in each class, any conclusions are tentative.

Claim. Across classes and questions, the greatest number of students received a score of ‘3’ for their claim (Fig. 5A). A number of students received a ‘1’ or ‘2’ and only four students received a ‘4’ for their claim.

In the ‘No Discussion’ class, two of the four students (50%) increased their scores (Fig. 5B). Students in the ‘Discussion without Talk Science’ class showed the greatest improvement in their claim scores on Question 2. In this class, four of the seven students (57%) increased their claim scores. In the ‘Discussion with Talk Science’ class, only two of the 11 students (18%) increased their scores.

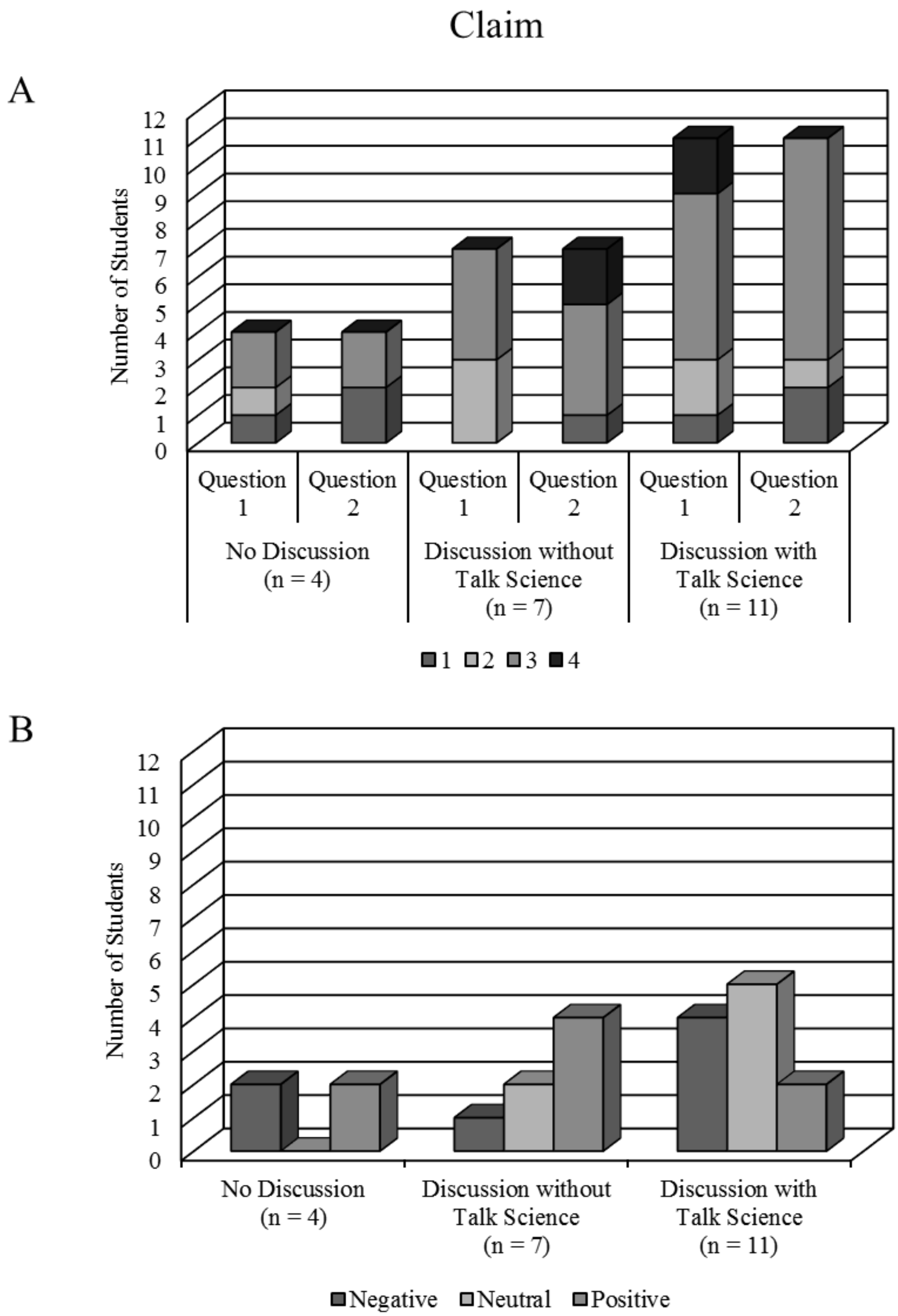


Figure 5. Claim scores received by high school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Evidence. Across classes and questions, the greatest number of students received a score of ‘1’ for their use of evidence (Fig. 6A). A number of students received a ‘2’ and only two students received a ‘3.’ No students received a ‘4’ for their use of evidence.

In the ‘No Discussion’ and the ‘Discussion without Talk Science’ classes, no students increased their evidence scores, but most remained neutral (75% and 71%, respectively) (Fig. 6B). Students in the ‘Discussion with Talk Science’ class showed the greatest improvement in their evidence scores on Question 2. In this class, six of the 11 students (55%) increased their evidence scores.

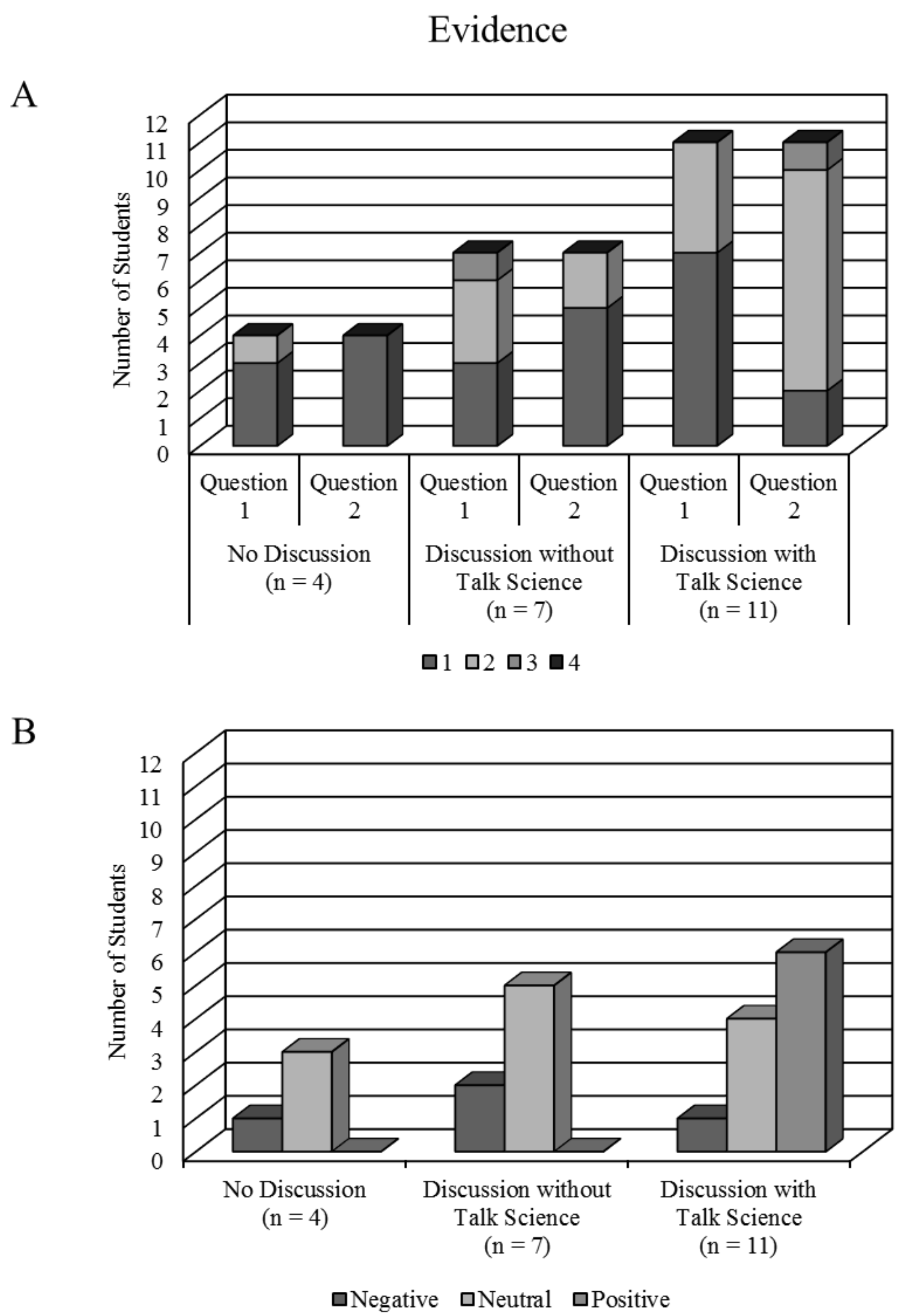


Figure 6. Evidence scores received by high school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Reasoning. Across classes and questions, the greatest number of students received a score of '1' for their use of reasoning (Fig. 7A). A number of students received a '2' and only four students received a '3.' No students received a '4' for their use of reasoning.

In the 'No Discussion' and the 'Discussion without Talk Science' classes, no students increased their reasoning scores, but most remained neutral (75% and 71%, respectively) (Fig.7B). Students in the 'Discussion with Talk Science' class showed the greatest improvement in their reasoning scores on Question 2. In this class, five of the 11 students (45%) increased their reasoning scores and the other six students remained neutral.

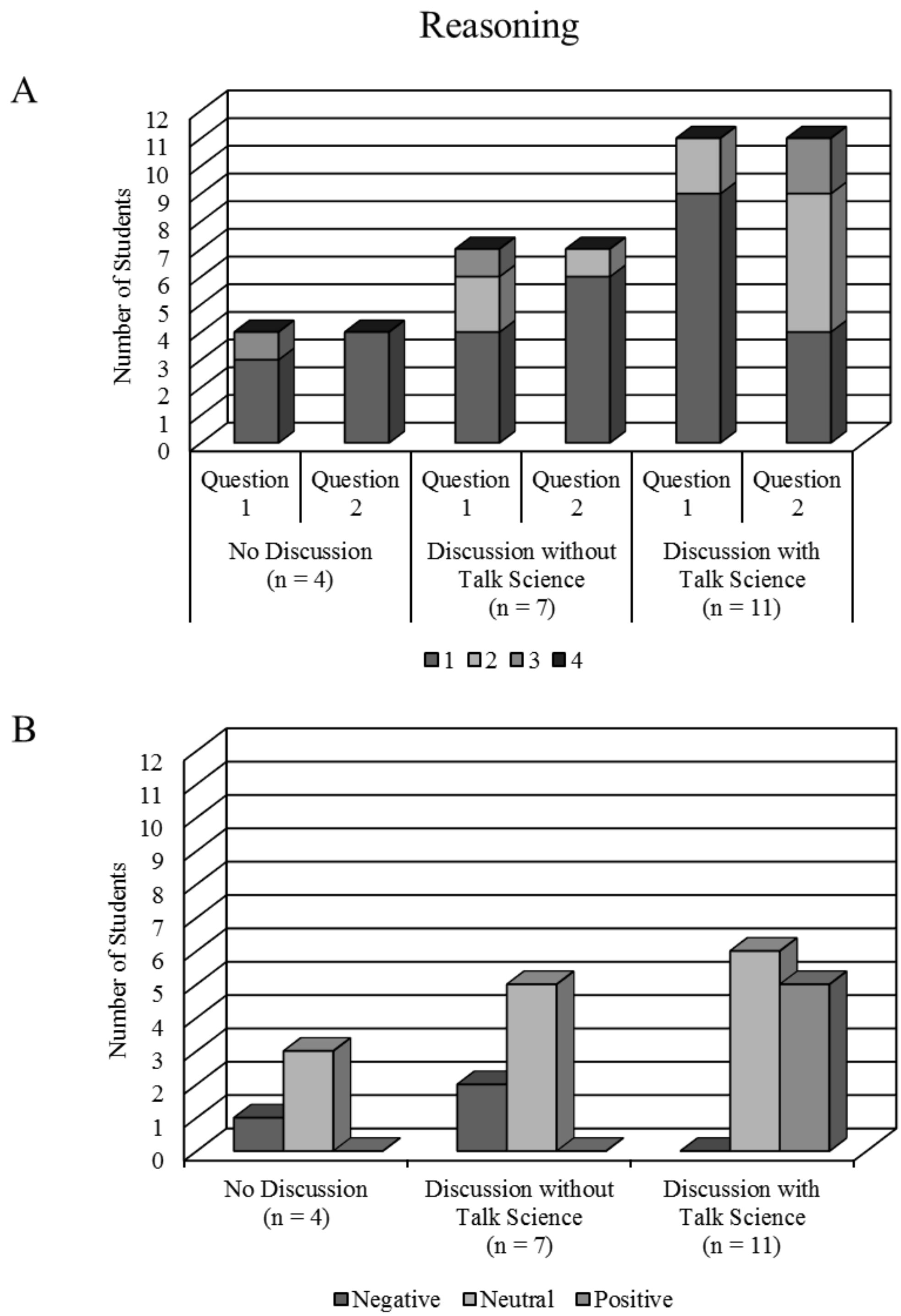


Figure 7. Reasoning scores received by high school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Content. Across classes and questions, the greatest number of students received a score of ‘2’ for their content knowledge (Fig. 8A). A number of students received a ‘1’ or ‘3,’ but no students received a ‘4’ for content.

In the ‘No Discussion’ class, two of the four students (50%) increased their scores (Fig. 8B). In the ‘Discussion without Talk Science’ class, only three of the seven students (43%) increased their scores. Students in the ‘Discussion with Talk Science’ class showed the greatest improvement in their content scores on Question 2. In this class, seven of the 11 students (64%) increased their content scores and the other three students remained neutral.

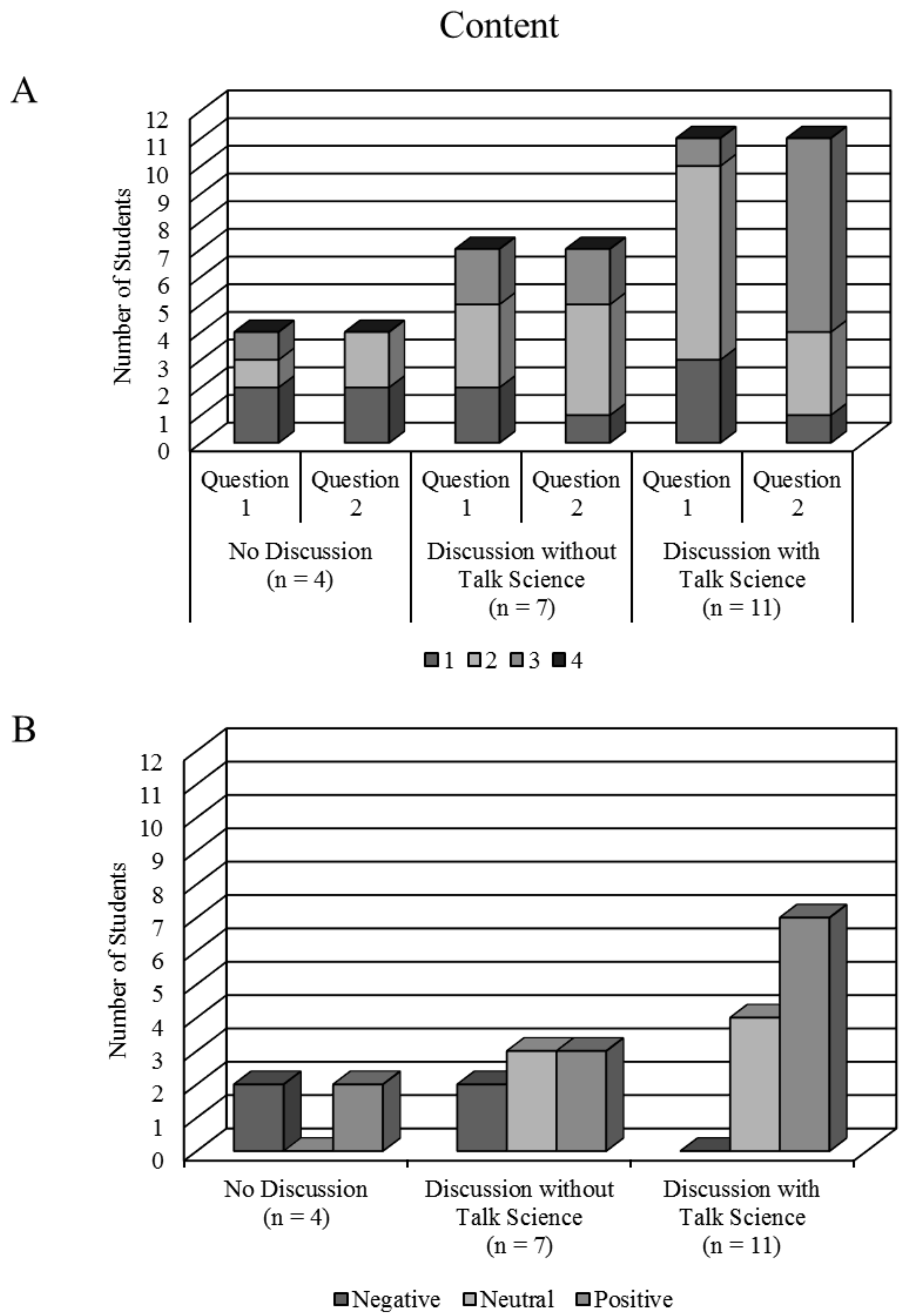


Figure 8. Content scores received by high school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Middle School

In the middle school section of this study, 40 seventh graders answered both questions and their scores are reported here. The ‘No Discussion’ class had 15 students, the ‘Discussion without Talk Science’ class had 10 students, and the ‘Discussion with Talk Science’ class had 15 students. Again, because of the small number of students in each class, any conclusions are tentative.

Claim. Across classes and questions, the greatest number of students received a score of ‘3’ for their claim (Fig. 9A). Among the other students, more students received a ‘4’ than received the lower scores of ‘1’ or ‘2.’

Students in the ‘No Discussion’ class showed the greatest improvement in their claim scores on Question 2 (Fig. 9B). In this class, nine of the 15 students (60%) increased their claim scores. In the ‘Discussion without Talk Science’ class, only one student (10%) increased his or her score. In the ‘Discussion with Talk Science’ class, seven of the 15 students (47%) increased their scores. In the two classes that had a discussion, more students remained neutral than decreased their score.

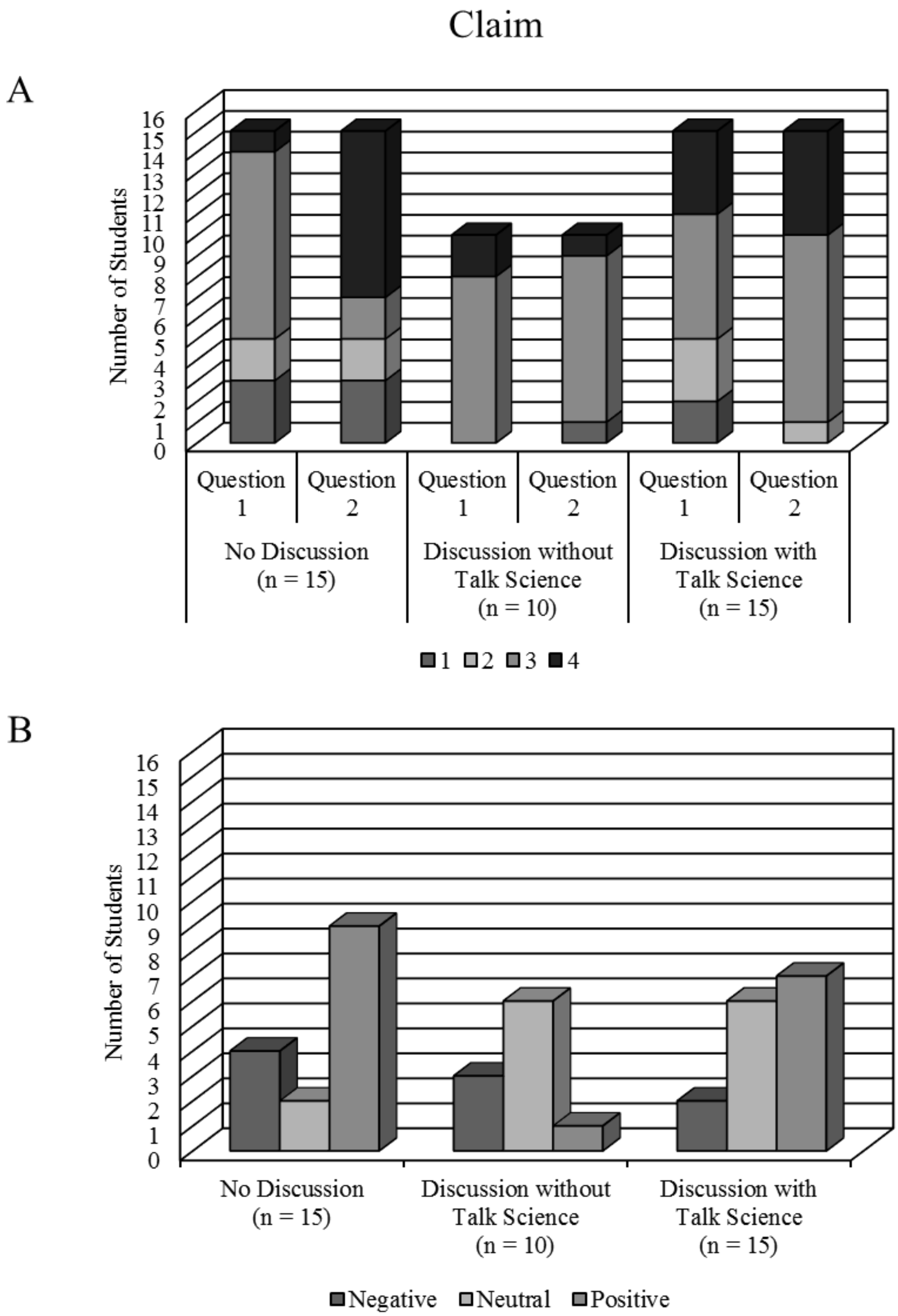


Figure 9. Claim scores received by middle school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Evidence. Across classes and questions, the greatest number of students received a score of '1' for their use of evidence (Fig. 10A). A number of students received a '2' and only two students received a '3.' No students received a '4' for their use of evidence.

Each of the three classes had two students who increased their evidence scores on Question 2 ('No Discussion' = 13%, 'Discussion without Talk Science' = 20%, and 'Discussion with Talk Science' = 13%) (Fig. 10B). In the 'No Discussion' and the 'Discussion with Talk Science' classes, most students (73% and 60%, respectively) remained neutral, while half of the students (50%) in the 'Discussion without Talk Science' class decreased their evidence scores.

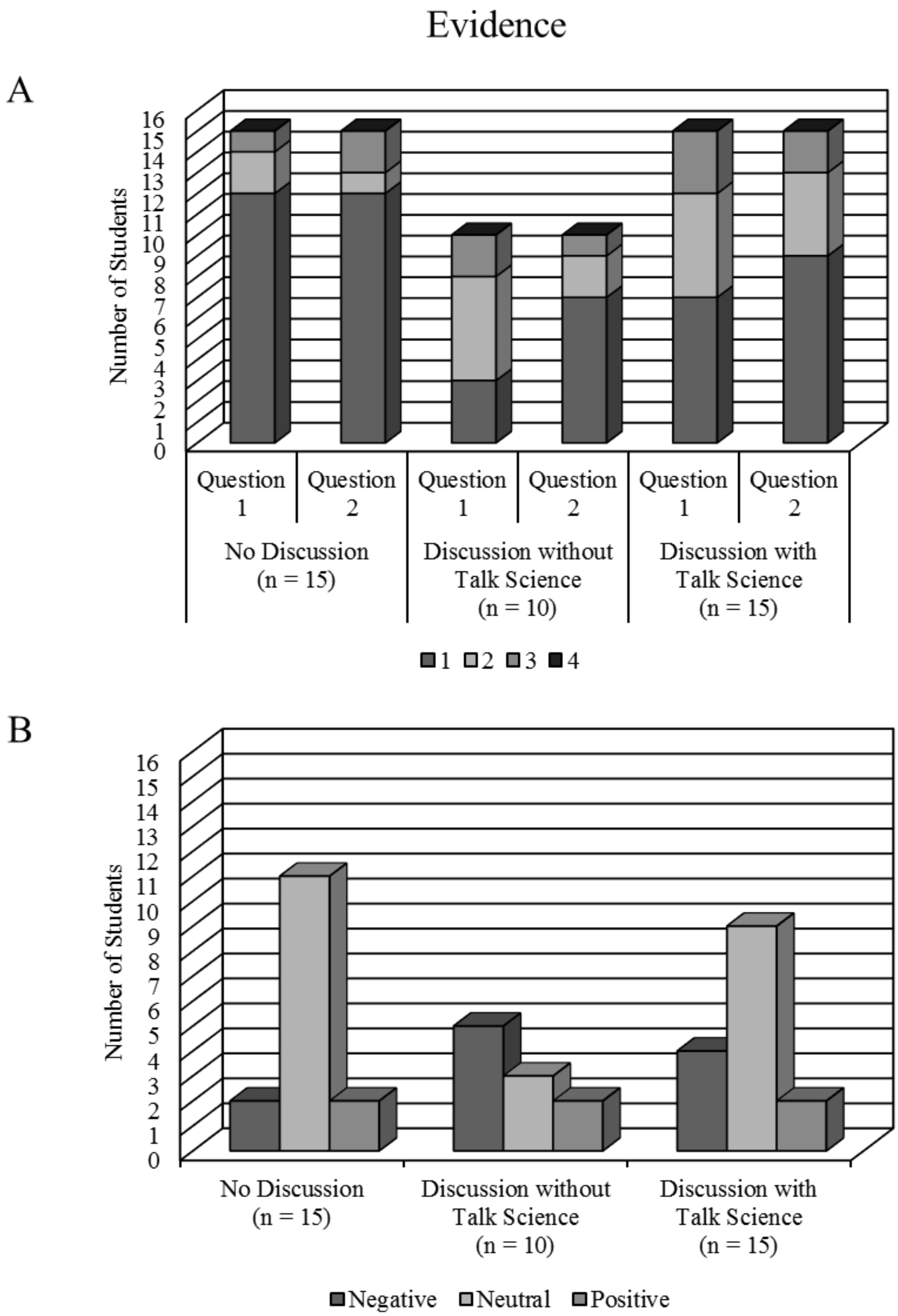


Figure 10. Evidence scores received by middle school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Reasoning. Across classes and questions, the greatest number of students received a score of '1' for their use of reasoning (Fig. 11A). A number of students received a '2' and fewer students received a '3' for their use of reasoning. Only two students received a '4' for their use of reasoning, though these scores were received for Question 1 when none of the classes had a discussion.

In the 'No Discussion' class, only one student increased his or her reasoning scores (7%) (Fig. 11B). Students in both classes that had a discussion showed the greatest improvement in their reasoning scores on Question 2. In the 'Discussion without Talk Science' class, two of the 10 students (20%) increased their reasoning scores and, in the 'Discussion with Talk Science' class, three of the 15 students (20%) increased their reasoning scores. The majority of students in all three classes had neither a positive nor a negative gain, but their scores remained neutral.

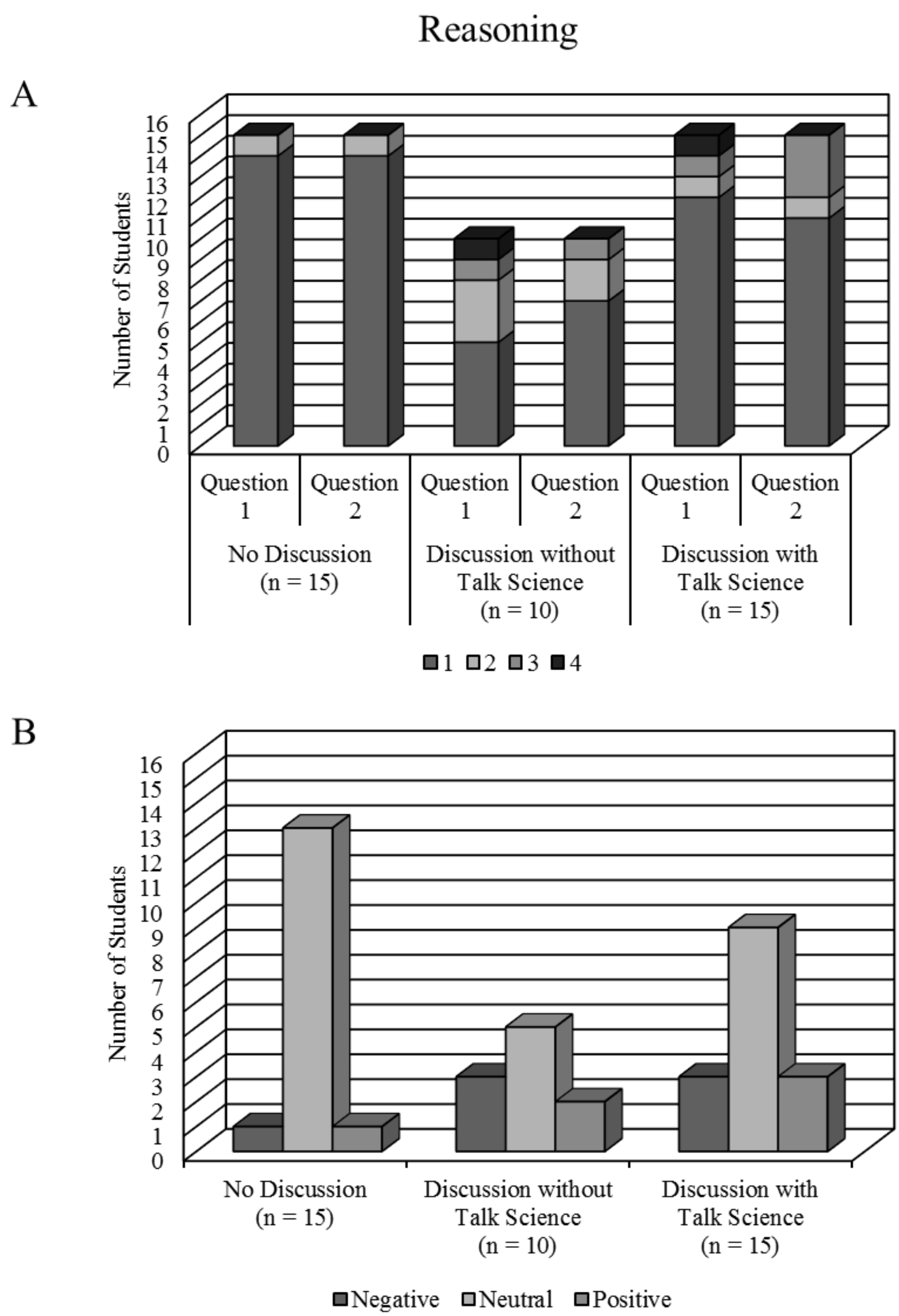


Figure 11. Reasoning scores received by middle school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Content. Across classes and questions, the greatest number of students received a score of '1' for their content knowledge (Fig. 12A). Slightly fewer students received a '2' and a small number of students received a '3' for their content knowledge. Only two students in the 'Discussion with Talk Science' class received a '4' for content, but both were earned for Question 1 when there was no discussion.

Students in the 'No Discussion' class showed the greatest improvement in their content scores on Question 2 (Fig. 12B). In this class, seven of the 15 students (47%) increased their content scores and the other eight students remained neutral. In the 'Discussion without Talk Science' class, three of the 10 students (30%) increased their scores. In the 'Discussion with Talk Science' class, five of the 15 students (33%) increased their scores.

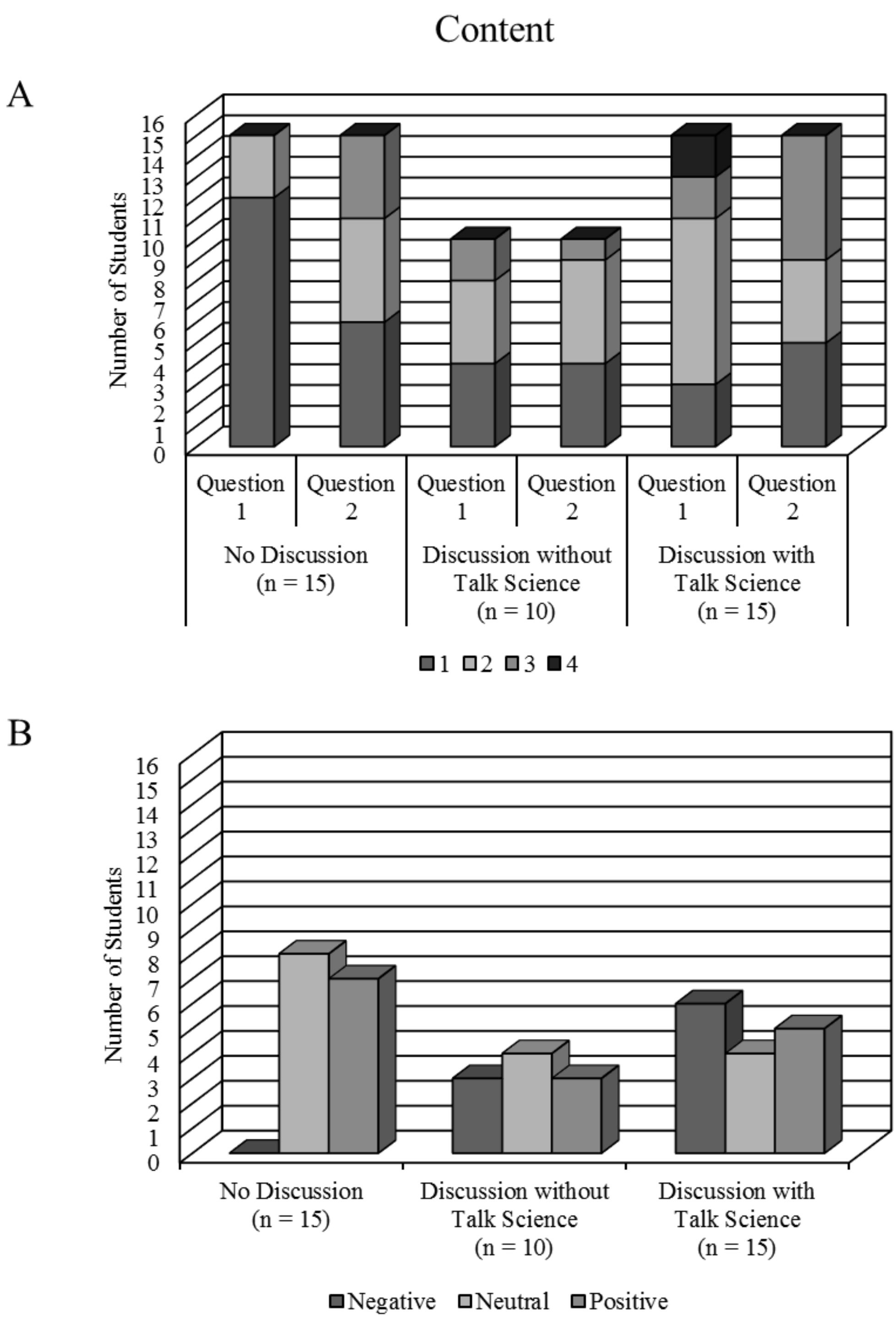


Figure 12. Content scores received by middle school students. A, Distribution of scores. B, Score gains between Question 1 and Question 2.

Discussion Reflections

Discussion reflections were written after students answered Question 2. The reflections reported here include those written by students who may not have answered Question 1 and, thus, are not included in the rubric scores presented previously.

High School

Discussion reflections were written by 25 high school students. Of these students, 22 students answered both Question 1 and Question 2 while three students only answered Question 2.

No Discussion. After answering Question 2, six of seven students in the 'No Discussion' class submitted discussion reflections (Fig. 13). One student did not provide a clear reflection and one student wrote a negative response. The other four students wrote positive reflections with two appreciating the answer and two appreciating the explanation.

Discussion without Talk Science. After answering Question 2, seven of eight students in the 'Discussion without Talk Science' class submitted discussion reflections (Fig. 13). Two students did not provide clear reflections, but no students wrote negative responses. The other five students wrote positive reflections with three appreciating the answer and two appreciating the explanation.

Discussion with Talk Science. After answering Question 2, 12 of 13 students in the 'Discussion with Talk Science' class submitted discussion reflections (Fig. 13). No students provided unclear reflections, but two students provided negative responses. The other 10 students wrote positive reflections with four appreciating the answer and six appreciating the explanation.

Middle School

Discussion reflections were written by 57 seventh grade students. Of these students, 40 students answered both Question 1 and Question 2 while one student only answered Question 1 and 16 students only answered Question 2.

No Discussion. After answering Question 2, all 19 students in the ‘No Discussion’ class submitted discussion reflections (Fig. 13). No students provided unclear reflections, but one student provided a negative response. The other 18 students wrote positive reflections with seven appreciating the answer and 11 appreciating the explanation.

Discussion without Talk Science. After answering Question 2, 19 of 20 students in the ‘Discussion without Talk Science’ class submitted discussion reflections (Fig. 13). Two students did not provide clear reflections and three students wrote negative responses. The other 14 students wrote positive reflections with seven appreciating the answer and seven appreciating the explanation.

Discussion with Talk Science. After answering Question 2, all 19 students in the ‘Discussion with Talk Science’ class submitted discussion reflections (Fig. 13). Five students did not provide clear reflections and three students wrote negative responses. The other 11 students wrote positive reflections with three appreciating the answer and eight appreciating the explanation.

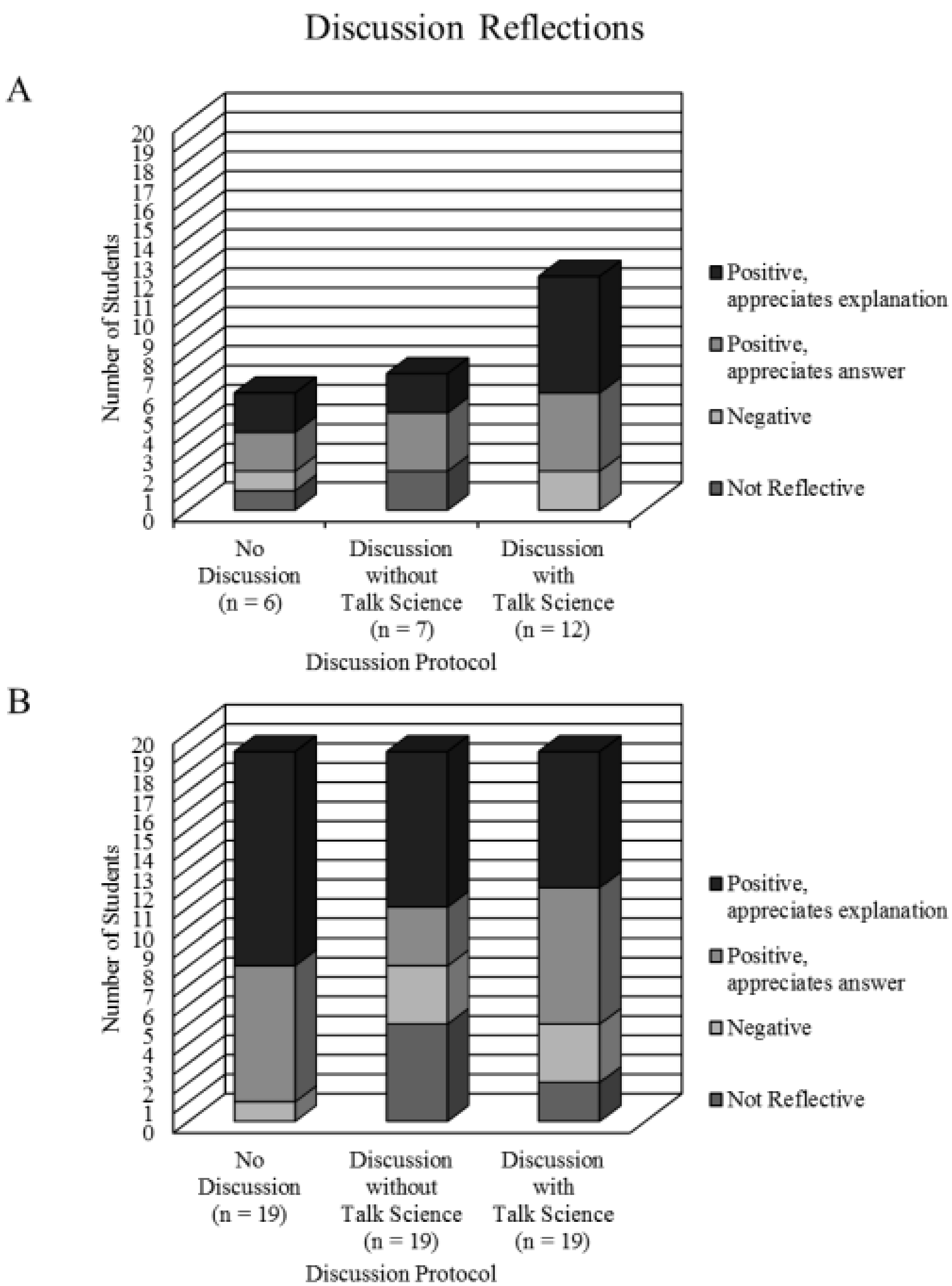


Figure 13. Discussion reflections scores. A, High school students. B, Middle school students.

Audio Recording

Discussion without Talk Science. In high school, the 'Discussion without Talk Science' class talked for 4:50 minutes. The teacher, Ms. Allen, spoke 26 times and used talk moves four of those times for a frequency of 15.4%. Two of these moves were from Goal 1 and two were from Goal 2 (Fig. 14). There was no student-student discussion.

In middle school, the 'Discussion without Talk Science' class talked for 3:17 minutes. The teacher, Ms. Johnson, spoke 15 times and used talk moves zero of those times for a frequency of 0.0% (Fig. 14). There was one instance of student-student discussion.

Discussion with Talk Science. In high school, the 'Discussion with Talk Science' class talked for 17:08 minutes. The teacher, Ms. Allen, spoke 76 times and used talk moves 18 of those times for a frequency of 23.7%. Of the 18 talk moves, six were from Goal 1, three were from Goal 2, three were from Goal 3, and seven were from Goal 4 (Fig. 14). The teaching partner spoke eight times and did not use talk moves. There was no student-student discussion; though, they did frequently provide answers simultaneously and talk over one another.

In middle school, the 'Discussion with Talk Science' class talked for 6:05 minutes. The teacher, Ms. Johnson, spoke 26 times and used talk moves nine of those times for a frequency of 34.6%. Of the nine talk moves, one was from Goal 1 and eight were from Goal 4 (Fig. 14). There were two instances of students using talk moves to further the discussion and two instances of student-student discussion.

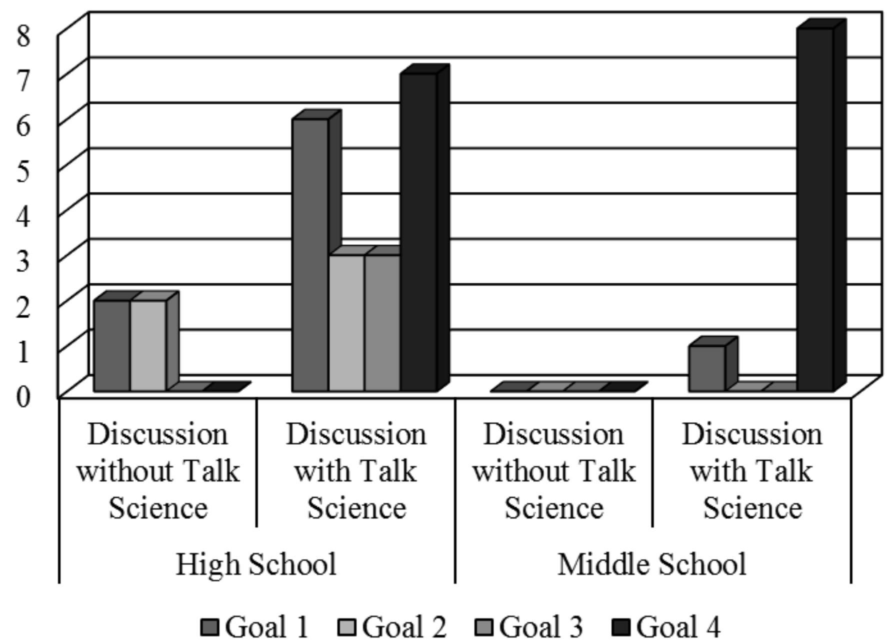


Figure 14. Teacher use of talk moves during classes with discussions. The goals are provided in Appendix G.

CHAPTER 4

DISCUSSION

Three aspects of this research are worthy of further discussion: 1) the findings that came from the data; 2) the research process from the perspective of researchers and teachers; and 3) possible impacts, including potential opportunities for future research.

Student Work

Student Responses to Questions

High School. In the ninth grade class that discussed with Talk Science, students showed improvement on evidence, reasoning, and content, which are the parts that Talk Science discussions are designed to emphasize (Michaels et al., 2008). In contrast, traditional call-and-response discussions often emphasize the claim, which is the only part that improved in the class that discussed without Talk Science. These call-and-response discussions do not push students beyond the claim to consider evidence and reasoning (Duschl & Osborne, 2002).

Student A11 participated in the discussion with Talk Science and is a typical example of a positive gain (Fig. 15). His or her score remained neutral for the claim, but improved for the other three categories—evidence, reasoning, and content. This student received a score of 3 for content because, even though he or she switched the movement associated with red and blue shifts, he or she explained the relationship between color, wavelength, and energy. Student A05 participated in the discussion with Talk Science and is a typical example of a negative gain (Fig. 16). His or her score remained neutral for the reasoning and content, but decreased for the other two categories—claim and evidence.

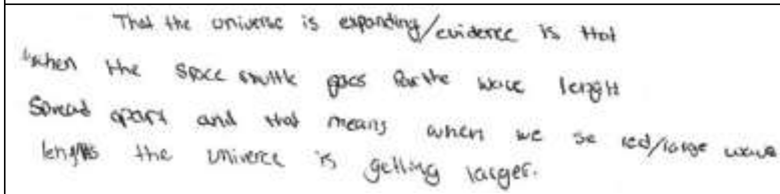
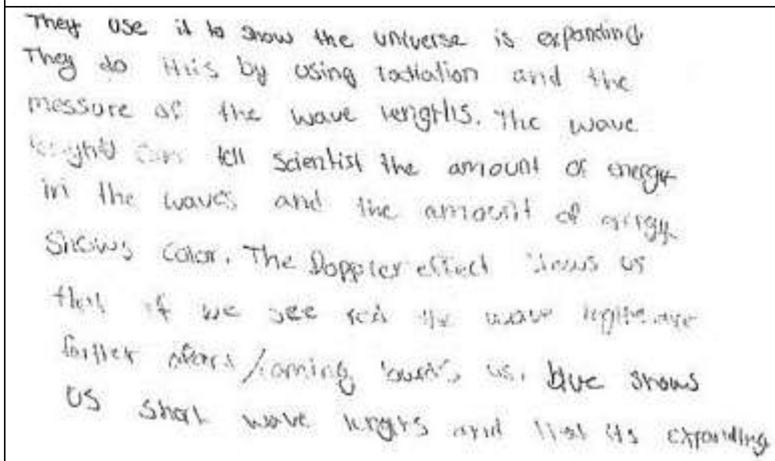
1. What do the movements of stars and galaxies tell astronomers about how the universe formed?	
	*That the universe is expanding/evidence is that when the space shuttle goes far the wave lengh spread apart and that means when we se red wave lengths the univerce is getting larger.*
2. How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?	
	*They use it to show the universe is expanding. They do this by using radiation and the measure of the wave lengths. The wave lengths can tell scientist the amount of energy in the waves and the amount of energy shows color. The Doppler effect shows us that if we see red the wave legths are farther apart/coming towards us. blue shows us short wave lengths and that its expanding.*

Figure 15. Responses written by high school student A11 that demonstrate positive gains. This student was in the 'Discussion with Talk Science' class. For Question 1, this student received the following scores: 3 (*Claim*), 1 (*Evidence*), 1 (*Reasoning*), and 1 (Content). For Question 2, this student received the following scores: 3 (*Claim*), 2 (*Evidence*), 3 (*Reasoning*), and 3 (Content).

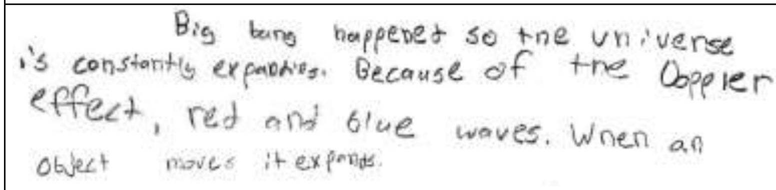
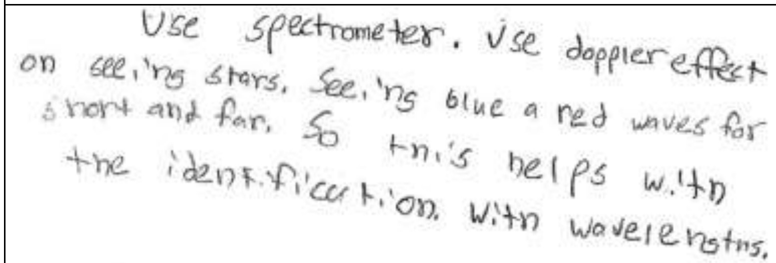
1. What do the movements of stars and galaxies tell astronomers about how the universe formed?	
 Big bang happenet so the universe is constantly expandies. Because of the Doppler effect, red and blue waves. When an object moves it expands.	*Big bang happened so the universe is constantly expanding. Because of the Doppler effect, red and blue waves. When an object moves it expands.*
2. How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?	
 Use spectrometer. Use doppler effect on seeing stars. Seeing blue a red waves for short and far. So this helps with the identification with wavelengths.	*Use spectrometer. Use doppler effect on seeing stars. Seeing blue a red waves for short and far. So this helps with the identification with wavelengths.*

Figure 16. Responses written by high school student A05 that demonstrate negative gains. This student was in the 'Discussion with Talk Science' class. For Question 1, this student received the following scores: 3 (*Claim*), 2 (*Evidence*), 1 (Reasoning), and 2 (Content). For Question 2, this student received the following scores: 1 (*Claim*), 1 (*Evidence*), 1 (*Reasoning*), and 2 (Content).

Middle School. Overall, middle school classrooms do not demonstrate the same pattern of improvement as the high school students. There were some examples, however, so this could potentially be a result of the questions selected. It appeared to be easier for students to make a satisfactory claim for Question 2; though, this did not seem to be the case for evidence, reasoning, or content. If the question was indeed easier, this could cause unintentionally higher scores on Question 2 and skew the data.

Student J57 participated in the discussion with Talk Science and is a typical example of a positive gain (Fig. 17). His or her score decreased for the claim, but improved for the other three categories—evidence, reasoning, and content. Student J12 participated in the discussion with Talk Science and is a typical example of a negative gain (Fig. 18). His or her score remained neutral for the claim and reasoning, but decreased for the other two categories—evidence and content.

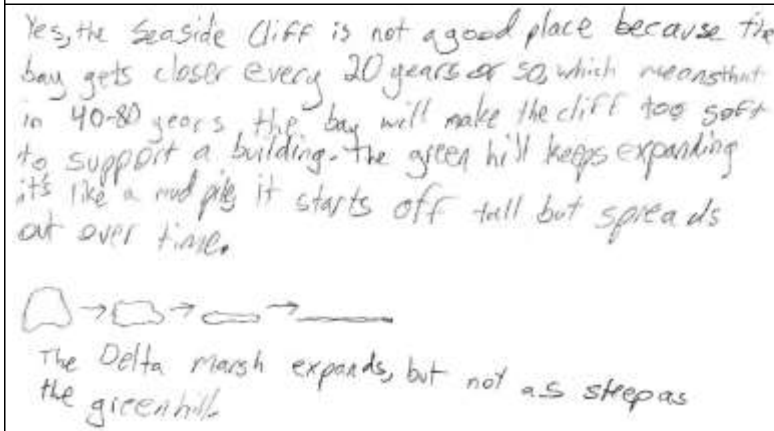
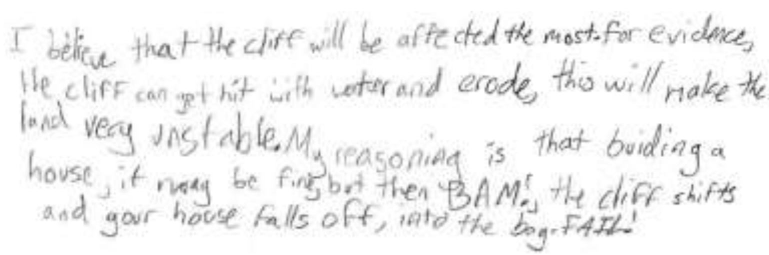
1. Do the maps indicate possible problems for building at any of the possible locations?	
	*Yes, the Seaside Cliff is not a good place because the bay gets closer every 20 years or so, which means that in 40-80 years the bay will make the cliff too soft to support a building. The green hill keeps expanding it's like a mud pile, it starts off tall but spreads out over time. The Delta marsh expands, but not as steep as the green hill.*
2. At which of the three building sites would you expect erosion and deposition to have the most effect on the land?	
	*I believe that the cliff will be affected the most. for evidence the cliff can get hit with water and erode, this will make the land very unstable. My reasoning is that building a house, it may be fine, but then BAM!, the cliff shifts and your house falls off, into the bay. FAIL!*

Figure 17. Responses written by middle school student J57 that demonstrate positive gains. This student was in the 'Discussion with Talk Science' class. For Question 1, this student received the following scores: 4 (*Claim*), 1 (*Evidence*), 1 (*Reasoning*), and 2 (Content). For Question 2, this student received the following scores: 3 (*Claim*), 2 (*Evidence*), 2 (*Reasoning*), and 3 (Content).

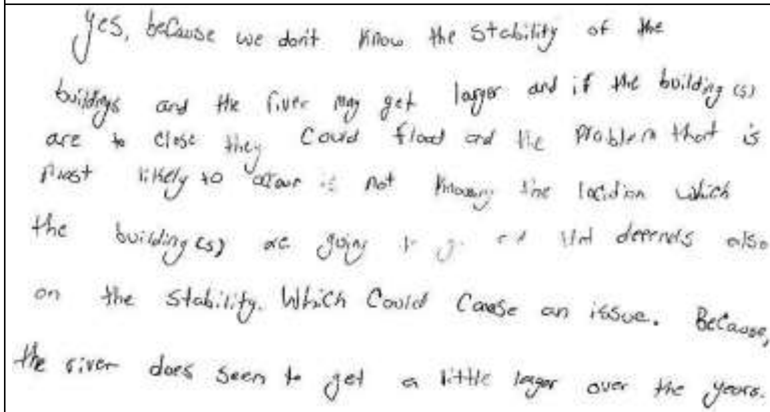
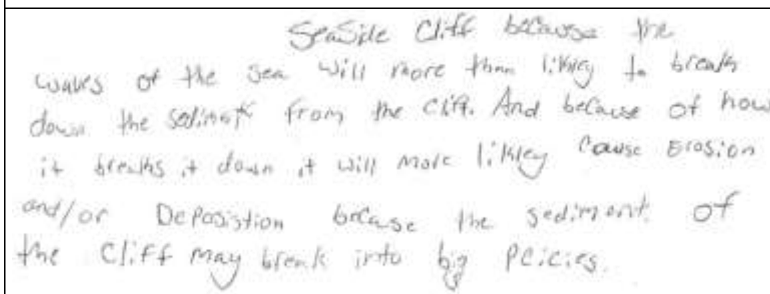
1. Do the maps indicate possible problems for building at any of the possible locations?	
	*Yes, because we don't know the stability of the buildings and the river may get larger and if the building (s) are to close they could flood and the problem that is most likely to occur is not knowing the location which the building (s) are going to (…) depends also on the stability. Which could cause an issue. Because, the river does seem to get a little larger over the years.*
2. At which of the three building sites would you expect erosion and deposition to have the most effect on the land?	
	*SeaSide Cliff because the waves of the sea will more than likley to break down the sediment from the cliff. And because of how it breaks it down it will more likley cause Erosion and/or Deposition because the sediment of the cliff may break into big peicies.*

Figure 18. Responses written by middle school student J12 that demonstrate negative gains. This student was in the 'Discussion without Talk Science' class. For Question 1, this student received the following scores: 4 (*Claim*), 2 (*Evidence*), 1 (*Reasoning*), and 3 (Content). For Question 2, this student received the following scores: 4 (*Claim*), 1 (*Evidence*), 1 (*Reasoning*), and 2 (Content).

Student Reflections about Discussion

Students were overwhelmingly positive when asked to reflect on the usefulness of a discussion. This was the case in both middle and high school and classes using any of the three discussion protocols. In high school classes, a higher percentage of students who had a discussion with Talk Science were positive (83.3%) than those who had a discussion without Talk Science (71.4%) and those who did not have a discussion (66.7%). Interestingly, this pattern was reversed in the middle school classes with the highest percentage of positive reflections coming from students who did not have a discussion (94.7%) and lower percentages of positive reflections from students who had a discussion without Talk Science (73.7%) or a discussion with Talk Science (57.9%).

Of the classes that had discussions, students who discussed with Talk Science were more likely to write reflections that suggested they appreciated the explanation more than the answer. For example, high school student A11, who was discussed above, seemed to value the discussion for helping him or her to "put together everything [he or she] learned" and even provided an example of learned content (Fig. 19). In two cases, students who discussed with Talk Science wrote negative reflections, such as that provided by A05 (Fig. 19), whose answers were also discussed above. Student A05's negative reflection corresponds with his or her negative gains for the written responses.

Both middle school students discussed above—J57 and J12—earned scores of 4 for their reflections (Fig. 20). These students valued their discussion similarly even though only J57 made positive gains on his or her written work while J12 had negative gains. Both students were in the class that had a discussion with Talk Science, so it is possible that J12's negative gains come from difficulty with the CER framework.

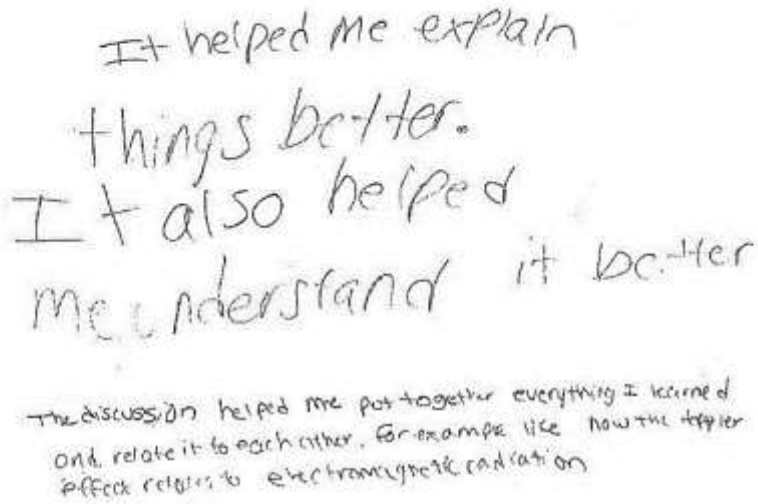
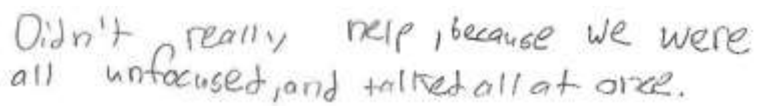
	How did your discussion help you write your answer?	
A11 2		It helped me explain things better. It also helped me understand it better. The discussion helped me put together everything I learned and relate it to each other. For example like how the doppler effect relates to electromagnetic radiation.
A05		Didn't really help, because we were all unfocused, and talked all at once.

Figure 19. Reflections written by high school students A11 and A05. Both of these students were in the 'Discussion with Talk Science' class. For the reflection, A11 received a score of 4* and A05 received a score of 2.

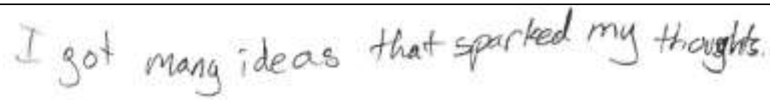
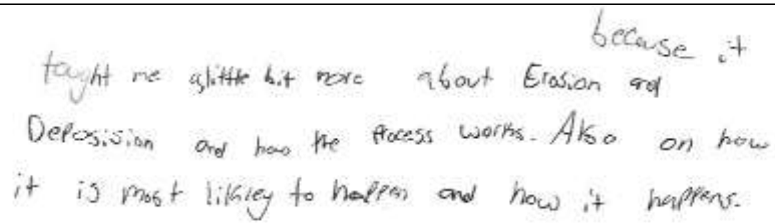
	How did your discussion help you write your answer?	
J57		I got many ideas that sparked my thoughts.
J12		because it tought me a little bit more about erosion and deposision and how the process works. Also on how it is most likley to happen and how it happens.

Figure 20. Reflections written by high school students J57 and J12. Both of these students were in the 'Discussion with Talk Science' class. For the reflection, both J57 and J12 received scores of 4.

Discussions that use Talk Science emphasize evidence and reasoning, which should produce greater understanding (Michaels et al., 2008). Often, during the course of this study, the MainePSP teachers reported resisting incorporating discussions in their classrooms because of the time commitment required and their perception that students do not benefit from the discussions. Both of these impressions have been documented among teachers and reported in the literature (Pimentel & McNeill, 2013). Here, it is shown that students do value discussions and that it might be worth the time commitment to have productive classroom discussions.

Audio Recordings of Discussion

High School. The high school discussion without Talk Science was characterized by the typical call-and-response interaction between the teacher and the students (Duschl & Osborne, 2002) (Fig. 21). Ms. Allen asked very direct questions and each response was brief. There was very little critical thinking apparent in the students' responses and there was no student-student interaction or building on other's ideas.

The high school discussion with Talk Science was more characteristic of the interactive discussion that was expected from Michaels et al. (2008) and Michaels and O'Connor (2012) (Fig. 22). Ms. Allen successfully used talk moves to encourage students to talk and share evidence and reasoning. Ms. Allen asked students to support their statements with evidence. Moreover, there was an example of student interaction when three students discuss wavelengths. This type of interaction among students is crucial for sociocultural learning (Newton et al., 1999).

MS. ALLEN: What comes from the sun?

3: Radiation.

MS. ALLEN: That's one. Radiation.

4: Infrared.

MS. ALLEN: Infrared. What else?

5: Heat.

6: Eyes. Light.

MS. ALLEN: What kind of light?

7: Visible light.

8: Blinding light.

MS. ALLEN: Ok. Visible light. So all these things that we're saying, what do we think they are?

9: Electromagnetic radiation?

MS. ALLEN: Yeah, ok, so let's talk about that a little bit more. So, tell me what you know about these electromagnetic radiation. So, we just said that it’s that visible light and then the waves that are outside of the visible spectrum. We just listed off a couple. So let's maybe talk about each one. So say one.

7: Visible light.

MS. ALLEN: What do we know about visible light?

7: You can physically see it. I don't know.

MS. ALLEN: Ok. What are the colors?

7: Red, orange, yellow, green, blue, purple and indigo.

Figure 21. Selected discussion from the high school class that discussed without Talk Science. Notice the short answers provided by the students and the lack of evidence and reasoning in their answers.

MS. ALLEN: Ok, so can someone that hasn't talked yet kind of bounce off of what he's saying with this red and blue shift?

49: Um///

50: It's closer when it's red. No///

MS. ALLEN: What might be your evidence?

Multiple Students: It's farther away when it's red and it's closer when it's blue.

51: Wavelength///

MS. ALLEN: Ok, Student 51 I like what you're saying. I agree with that, but can you give me some more evidence behind that?

51: The wavelengths will be bigger wavelengths when it's red and smaller wavelengths when it's blue.

52: The other way around.

51: Or the other way around.

53: No, she was right.

MS. ALLEN: No.

51: I was right. Don't laugh at me.

52: I wasn't laughing

MS. ALLEN: No more. Student 54, can you resay what she just said?

54: When you see red, the wavelengths are further apart. When you see blue, the wavelengths are closer apart.

Figure 22. Selected discussion from the high school class that discussed with Talk Science. Notice the more in-depth answers provided by the students and the interaction as Students 51, 52, and 53 discuss wavelengths.

Middle School. The middle school discussion without Talk Science also was characterized by the typical call-and-response interaction between the teacher and the students (Duschl & Osborne, 2002) (Fig. 23). As with the high school class, Ms. Johnson asked very direct questions and moved from one student to the next. Each student offered a statement, but was not asked to support it with evidence or reasoning. There was an attempt at student-student interaction, but the second student was reaffirming the first statement and did not constructively advance the conversation.

The middle school discussion with Talk Science was more characteristic of the discussion that was expected from Michaels et al. (2008) and Michaels and O'Connor (2012) (Fig. 24). In this case, Ms. Johnson used talk moves, but did not stimulate interactive discussion and did not push the students to use evidence and reasoning. Although the students provided more thoughtful responses, they did not have a more productive discussion in terms of argumentation.

3: What was the question again?

MS. JOHNSON: How do erosion and deposition affect our landscape?

4: Well...um///

5: I know the answer.

4: I know what I want to say.

(Classroom management)

MS. JOHNSON: Student 4, I'm sorry for interrupting. I can come back to you, too.

4: Ok.

MS. JOHNSON: Um, oh, Student 7.

7: Erosion breaks things down, so that can cause a bunch of different things to happen///

8: Yeah, like if there was a (…) or something, it would be like crumble, crumble, crumble.

MS. JOHNSON: Ok.

7: And, deposition moves things around.

MS. JOHNSON: Ok, thank you.

8: Me?

MS. JOHNSON: Yep.

8: Erosion can damage like houses and um...like land.

MS. JOHNSON: Thank you.

Figure 23. Selected discussion from the middle school class that discussed without Talk Science. Notice the less thoughtful responses and the punctuated movement from one student to the next.

MS. JOHNSON: Student 1, let's start us off.

1: Well, like, the erosion, like, like even like, make like, it can take out like, places like built, like if there's like buildings or something, like erosion happens, it'll wipe the building out. And, like the deposition, could like carry it away and then like (...) something bigger or like could clog something and, yeah, that's my thought.

MS. JOHNSON: Ok...Student 2, you can respond to what he has said or you can respond with a new idea.

2: I'm going to respond with a new idea.

MS. JOHNSON: Ok.

2: Um, if there's like a river and like rocks at the top, the river would like, would like slide up against you or whatever, the water, it would like break particles down and stuff and then it could like, like the river's going this way, but everything could break off that way or something, like make a new landform. That'd be cool.

MS. JOHNSON: Who would like to add on to what Student 2 has said or a new idea? Student 3? So, how can you add on to what he said, either by saying "I agree with you, Student 2, because///"

3: I agree with you, Student 2, because///

MS. JOHNSON: And, because?

4: Because he's awesome

Figure 24. Selected discussion from the middle school class that discussed with Talk Science. Notice the more thoughtful answers, but the lack of evidence and reasoning.

Analysis of Research Process

Collaboration

This study involved teachers and researchers at each step in the process as is suggested in DBIR (Penuel et al., 2011). A team of teachers worked to identify the problem of interest and the integration of Talk Science and the CER framework. A team of graduate students worked alongside the teachers to select the questions, design the rubric, and score the student work. This collaboration was beneficial because it included both perspectives and greatly improved the research project. For example, the reflection question that was asked of the 'No Discussion' classes was a last-minute addition by the ninth grade teacher and provided a comparison between those students who discussed before writing and those who did not.

Question Selection

Written responses were collected using questions selected from the existing curricula that were in place in the classrooms. Existing questions were selected to minimize classroom disruption during data collection. The high school questions were selected by a group of teachers and researchers. However, the middle school questions were selected only by researchers and these questions, particularly the second question, proved difficult to write using a CER framework and was equally difficult to score using the rubric. In this case, it was much more beneficial to have the teachers involved in this step of the process. In the future, it will be important to ensure that the questions are truly comparable.

Rubric Design

The final rubric was designed through a collaborative effort between teachers and researchers. Initially, the researchers recommended a draft rubric that the teachers thought underestimated the work of the students. After many drafts, the final rubric was agreed upon for data scoring. A few important aspects of research design were brought up by teachers that the researchers would not have considered. For instance, in their classrooms, many high school teachers consider all data to be potential evidence, but not all evidence to be data, so that data are only quantitative, while evidence may be qualitative or quantitative.

In the end, though the rubric was suitable for the research, the teachers decided it was not appropriate for use as an assessment tool in the classroom. Some teachers had difficulty focusing on the structure of the written work while disregarding the content. They also found it challenging to look at the parts of the argument separately rather than 'grading' the responses as a whole. The rubric could easily be modified to be appropriate for use in assessing student work and some of the teachers mentioned that they would consider that in the future. Even without use in the classroom, the co-design process of the rubric was important professional development for teachers and researchers.

Class Selection

In both the middle and high school classrooms, the teachers selected which of their classes participated in which discussion protocol. It is unknown how the seventh grade teacher assigned discussion protocols. In the ninth grade classroom, this meant that the Honors class, which was described as more talkative, received a discussion with Talk Science and the college prep class, which was described as quieter, did not have a discussion. In this case, it is possible that there is a correlation between achievement and gains made between the two questions. In the future, it might be best to mix achievement levels for the purposes of data collection so that this is no longer a contributing factor.

Implementation

For any research that relies on instructional frameworks, it is important that students be familiar and have some experience with them prior to data collection (Driver et al., 2000; McNeill & Krajcik, 2012). For the study here, it was preferred that the teachers establish discussion and argumentation norms in their classrooms early. Because of the data collection timeline, this was not possible for the ninth grade class that is studied here. However, the use of these frameworks in a non-research manner requires that these norms are consistently maintained throughout the school year and that students are given adequate opportunities to practice developing their skills (Driver et al., 2000; McNeill & Krajcik, 2012).

A large number of variables are present when research is conducted in the classroom. Here, each teacher collected data within his or her own classroom. To standardize this data collection, it might be more meaningful to use the same person (researcher or teacher) in each classroom. This person could define the protocols and maintain consistency across classrooms and grades. In addition, this person could be sufficiently trained to use Talk Science. Teachers who participated in this study were asked to self-report their Talk Science ability prior to implementation and inaccurate reporting could create problems with discussions and students' work. Nevertheless, by using the research protocol with a variety of teachers, it was possible to consider the robustness of the findings across classrooms.

An additional middle school teacher participated in the study, but, because of a miscommunication, data were not collected according to the established procedure. This teacher had three sixth grade Earth Science classes that used the same SEPUP curriculum as the seventh grade classes. Unfortunately, the sixth grade teacher divided her students into small groups instead of conducting a whole-class discussion. She also did not use the prompt question, but had her students discuss the second question before writing about it. This shift in protocol removed the critical thinking component of argumentation. For these reasons, it is incredibly important to outline instructions and make expectations clear.

Analysis

For scoring, there were minimal issues with the rubric, which should be addressed in future iterations of this study. Primarily, by assuming that the first sentence is the claim, the score for claim is most likely an inaccurate representation in a number of cases. This assumption was sufficient for most of the scoring, but researchers later noticed that some responses provided evidence within the first sentence and, thus, could not be scored as 'evidence.' These sentences often included the word 'because' and, thus, the beginning of the sentence should be scored as a claim and the end of the sentence should be scored as evidence. This is consistent with suggestions made by McNeill and Krajcik (2012).

In addition, middle school students frequently fell short of achieving the next higher score. Because the rubric was initially designed to score data from ninth grade classrooms, it may have been insufficient for scoring the work of middle school students. In future iterations of this study, the rubric could be adapted to be grade-specific or to differentiate between middle and high school. Additionally, if the rubric was redesigned, actual student work could be used to validate the rubric and ensure that these students are more accurately scored.

Teacher Perspective

Classroom Instruction

The ninth grade teacher, Ms. Allen, reported that her students are taught to use the Claim, Evidence, Reasoning framework through continuous practice with GeoLog questions. These were scored separately from the rest of the GeoLog to encourage students to use the format and to think more critically. Ms. Allen taught Talk Science by allowing the students to reference a checklist during discussions and requiring each student to speak at least once. At this school, students cannot be graded on participation, so this was not a technique used to teach discussion methods.

The seventh grade teacher, Ms. Johnson, reported that her students were taught to use Claim, Evidence, Reasoning using writing frames to provide support, particularly for thinking about claims and evidence. Over the school year, Ms. Johnson modified the writing frame to allow students more flexibility with their own writing and eventually included reasoning. Ms. Johnson taught her students how to discuss by using feedback, guidance, and modeling. She did not focus on the specific talk moves, but encouraged students to share ideas and to offer disagreements in order to learn from each other.

Ms. Allen used Talk Science once every 2-3 weeks in her classroom. Ms. Johnson attempted to use some of the moves in daily discussions, but she reported focusing on moves that are “just good practice.” This could explain her frequent use of the “add-on” move during her ‘Discussion with Talk Science.’ Importantly, this study was completed at the beginning of the school year, which most likely limited the learning opportunities that students of both grades experienced with CER and Talk Science.

Study Implementation

Ms. Allen described how her ninth grade classroom looked during both discussion-based sections. In the ‘Discussion without Talk Science,’ the students sat in somewhat of a circle. The chairs were not moved from their normal positions. There were no students in the middle of the group, but Ms. Allen was near the front and led the discussion. In the ‘Discussion with Talk Science,’ the students pushed their desks together to form a tighter circle. Ms. Allen did not join the circle, but facilitated the discussion from outside of the group of students.

Ms. Johnson maintained the same classroom layout in both of the seventh grade discussion-based sections. Her classroom has six large lab tables with approximately four students at each table. She was unable to recall if she was at the front of the classroom or if she was seated with the students.

Study Review

Ms. Allen liked the different discussion groups, but thought that there should be more requirements for the teachers to increase the consistency of the study. She recommended having teachers practice the procedure in the classroom for three times before collecting data. This would have helped address problems encountered by the sixth grade teacher whose data had to be disregarded. Ms. Allen also had concerns about the questions selected for data collection because not all of the GeoLog questions are suited for Talk Science discussions. She did like the rubric used for scoring student responses and described it as “kid friendly and [possible] to reach a 3.” Ms. Allen was interested in participating in future iterations of this study.

Ms. Johnson thought the study was interesting in that it looked at differences in the discussions, but she reported that it was difficult to refrain from using talk moves in the class that had a discussion without Talk Science. She felt that it was hard to collect data while also focusing on her regular responsibilities and that an assistant in the classroom would be beneficial in the future. Ms. Johnson did think that the rubric was appropriate for the grade level and that it was useful as a teacher. She would be willing to participate in this study again, if someone visited her classroom to collect the data or if there was a tool that she could use to more easily collect data.

Impact of Research

Classroom Instruction

When implementing new instructional methods, such as Claim, Evidence, Reasoning and Talk Science, it is imperative that teachers thoroughly introduce the frameworks and consistently revisit them throughout the school year (McNeill & Krajcik, 2012). Furthermore, students’ use of these frameworks can be improved by receiving detailed feedback from teachers (McNeill & Krajcik, 2012). The findings presented here demonstrate that students can benefit from these frameworks even when they are unfamiliar. If students are given proper instruction and scaffolding, these frameworks could become normalized in the classrooms. This includes setting norms and using them regularly as well as providing feedback during discussions and on written work.

Professional Development

The results of this study can be used to influence professional development for teachers and administrators in the MainePSP and, for this purpose, it is beneficial to have the teachers' input throughout the process. Because teachers find it difficult to leave "traditional" discussion, it is important that inclusion of science discussion does not rely solely on curriculum changes, but also include continuous, long-term professional development support to change teacher behaviors in the classroom (Pimentel & McNeill, 2013).

Simon et al. (2006) demonstrated that teachers often have different ways of implementing new ideas and that these differences should be recognized when planning professional development. Moreover, professional development should include teachers' future knowledge and their goals so that argumentation processes can be encountered hierarchically (Simon et al., 2006). Also, in addition to learning the discussion-facilitating moves, teachers should learn the negative moves, such as teacher elaborations and interruptions, which hinder student discussion (Pimentel & McNeill, 2013).

Future Work

The study reported here will be used as a catalyst for future research projects. Additional data were collected during the spring of 2016 from the students of two ninth grade teachers who are not part of the MainePSP. These teachers also teach Earth Science, but use a different curriculum and do not participate in the professional development network. In all, responses and reflections were collected from 109 students and will be analyzed in the near future. This additional data will allow for a comparison to be made between students within and outside of the MainePSP.

In the future, more longitudinal data should be collected to get a more accurate representation of the impact that discussion can have on written work. The MaineESP has successfully implemented Talk Science in K-5 classrooms and, as these students progress through middle and high school, it would be particularly interesting to investigate their writing as they gain experience using the Claim, Evidence, Reasoning framework.

In addition, it would be beneficial to have more self- and peer-analysis done by both teachers and students. It would be interesting to know how teachers interpret their own use of Talk Science, but it also might be helpful for teachers to give one another feedback on their use of Talk Science in the classroom. MainePSP teachers suggested that it might benefit students to evaluate their own, as well as one another's, writing using the CER framework.

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APPENDIX A: MODULE 1 GEOLOG 1.1-3

Name: ______________________________ Period:__________

Chapter 1 Astronomy
Section 3: Origin of the Universe and the Solar System
Section 1: Size and Scale of the Universe
Adapted from EarthComm, Second Edition, ©2012

What do you see? (Using the image above, please make 2 or more inferences and include the observations that led to that thinking.)	
Observations:	**Inference:**

Learning Targets Pre Self Assessment (I can):	U	N	S	E
1. Investigate the current theory about the formation of the universe (Big Bang) and the evidence that supports it. (1.3)				
2.Perform an experiment that explains universal expansion. (1.3)				
3. Compare and contrast how distances are measured in space. (1.1)				

Think About It
(Use the information below, the picture above, and your prior knowledge to create reasonable answers to the following questions.)

When you think you are standing still on Earth, you are actually moving rapidly through space. Earth rotates once about its axis every 24 hours and revolves around the Sun once every 365 days. You are gaining a lot of mileage without taking a step. When you look up at the stars in the sky, they also seem to be still, although they are moving through space at incredible speeds.

What do the movements of stars and galaxies tell astronomers about how the universe formed?

1

How did the solar system form?

What is the probability that there are planetary systems beyond our own? How do you know?

Getting Started

Wave Basics

For background on the basics of wave mechanics, use the following website:
http://phet.colorado.edu/en/simulation/wave-on-a-string

Show your understanding by completing the short tutorial: http://phet.colorado.edu/files/activities/3581/Wave%20on%20a%20String%20Student%20Learning%20Guide.docx.

For background on the electromagnetic spectrum, use the following website:
http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html

Investigate

In this Investigate, you will explore how the universe formed and continues to expand. You will then run a model that examines how scientists measure the motion of stars and galaxies. Finally, you will observe a model that demonstrates how the solar system formed.

Part A: Demo of Evidence of Motion

1. Scientists have found that the motion of a star or galaxy relative to Earth can be determined by a shift in the wavelength of the light it emits. Your teacher will model this effect using sound. They will swing an alarm clock, buzzer, or constant-pitch noisemaker around on a string. You will stand outside the reach of the swinging noisemaker.

    a) How will the circular swinging of the noisemaker affect the sound it produces? Record your prediction.

2. Turn on the noisemaker and observe the sound it makes when stationary.

3. Attach a string securely to the noisemaker. Your teacher will swing the noisemaker around on the string while you stand outside its reach.

a) How does swinging the noisemaker affect the pitch of the sound that is heard?

b) Explain your observations.

c) What other changes in pitch have you observed from an object in motion?

4. Now go to this link and fill in the table below:
http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::800::600::/sites/dl/free/0072482621/78778/Doppler_Nav.swf::Doppler+Shift+Interactive

Approach	Observations of Frequency	Observation of Wavelength
Observer Approach		
Source Approach		
Both Approach		

Part B: Model of an Expanding Universe

1. Many astronomers theorize that our universe is expanding. They support their ideas by observations of distant galaxies that appear to be moving away from our galaxy at enormous speeds. You will use a large balloon, marker, and tape measure to model the movement of galaxies away from each other as the universe continues to increase in size.

Mark 10 dots in a straight line from **<u>end of the neck of the balloon (where it starts to get round approx. 4cm) to the top</u>** evenly on the surface of the deflated balloon. Label the dots with letters starting with A and ending with J. The dots represent galaxies. Galaxy A is the Milky Way Galaxy.

a) Predict what will happen to the distances between the galaxies as the balloon is inflated.

2. Have one person from your group inflate the balloon until its diameter is **about 20 cm**. Pinch the opening of the balloon to keep air from leaking out.

3. Have another person use a tape measure to measure the distance from the Milky Way to each of the other galaxies. Galaxy A is the Milky Way. You will measure the distances from the Milky Way (Galaxy A) to each of the other 9 galaxies in centimeters.

a) Record your measurements in the data table below in the row labeled "Expansion Time 1."

4. Inflate the balloon until its diameter is **about 28 cm**. Pinch the opening of the balloon to keep air from leaking out.

a) Record the new distance from the Milky Way to each of the other galaxies. Record your measurements in the data table in the second row labeled "Expansion Time 2."

5. Calculate the increase in distance between expansion times. Do this by subtracting the distance for each galaxy at "Expansion Time 1" from the distance for each galaxy at "Expansion Time 2."

a) Record the increase in distances in the data table in the third row.

6. Assume that the time between expansions was a period of 8 years. Calculate the speed that each galaxy moved away from the Milky Way using the equation:

$$speed = \frac{distance}{time}$$

a) Record this rate of expansion in the fourth row of your data table.

7. Use the rates to calculate how far each galaxy will be from the Milky Way after 24 years and after 32 years.

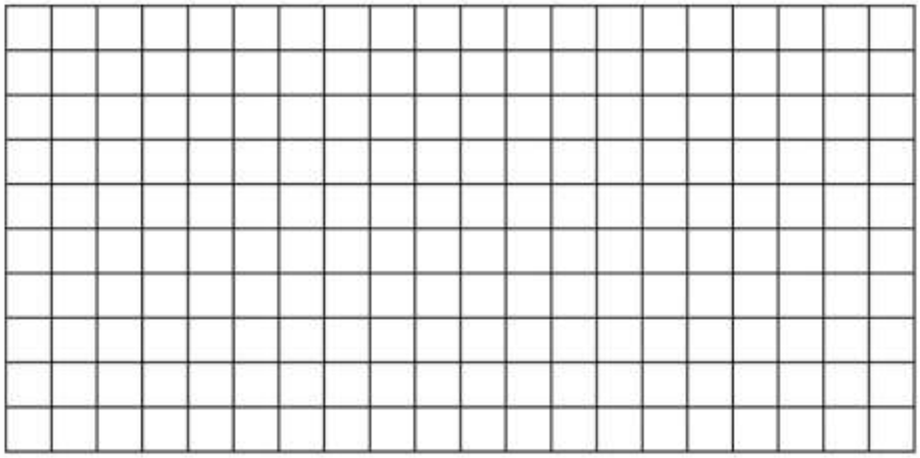
a) Record these distances in the table.

4

Distance From…..	Galaxy A-B	Galaxy A-C	Galaxy A-D	Galaxy A-E	Galaxy A-F	Galaxy A-G	Galaxy A-H	Galaxy A-I	Galaxy A-J
Expansion Time 1 (20cm)									
Expansion Time 2 (28 cm)									
Increase in distance (Time 2- Time 1)									
Rate of expansion (Distance/ 8yrs)									
Distance after 24 yrs (Rate X 24yrs)									
Distance after 32 yrs (Rate x 32yrs)									

5

8. Create a line graph to plot the data from your table. Place the time (0, 8, 16, 32 years on the x-axis and distance in centimeters on the y-axis. You will plot a separate line for each galaxy.



8. Use your results and the graph you created to help you answer the following questions:

a) How do the distances from the Milky Way Galaxy to the other galaxies change over time?

b) If the universe is expanding, do galaxies that are close together move apart faster or slower than galaxies that are far apart?

Digging Deeper

Read pages 32-35 in your text on the Formation of the Universe, Solar System, and Planets. Use the following to organize the information presented.

Big Bang Theory (define)-

Scientists estimate the universe to be approximately ____________________ years old.

Evidence for the Big Bang Theory

Form of Evidence:	Explain what it is.	How does this support the Big Bang theory?
Doppler Effect		
Cosmic Background Radiation		

Three possible outcomes for the fate of the universe (page 35):

1.

2.

3.

Recent observations show...

Summarize Nebular Theory (the steps by which our solar system formed from a giant cloud of gas and dust) pages 35-37:

The Birth of the Planets (pages 37-40)

	Description	**Detail (location, reason, example, etc)**
Terrestrial Planets		
Gas Giant Planets		
Comets		
Asteroids		
Extrasolar Planets		

What is the Difference Between a Law and a Theory? (page 40) To determine the difference, describe what each term IS as well as what each IS NOT.

	IS…	*IS NOT…*
A Scientific Law		
A Scientific Theory		

8

Checking Up:

1. What is the Doppler effect?

2. Which way are most galaxies moving relative to each other?

3. What is the origin of the cosmic background radiation?

4. What is a nebula?

5. Explain why the material surrounding a young star forms a disk.

6. Which elements are primarily involved in the Sun's fusion reaction?

Investigate, cont.

Part C: Measuring Distance with Time

1. In your group, record the distance in meters you can walk heel-to-toe for 30 seconds. Multiply this by 2 to get student meters/ min. Repeat for a total of 3 trials and find the average.

   Trial 1: _____________m x 2 = ______________m/min

   Trial 2: _____________m x 2 = ______________ m/min

   Trial 3: _____________m x 2 = ______________ m/min

   Average= ______________ m/min

2. Using your average as your value of a **student-minute**, solve the following (Show work!!):

    a. You have 5 minutes to travel between classes. How far can you travel during this time?

    b. If you stop to talk to your friend for 3.5 minutes between periods 1 and 2 and you need to travel 150 m to your next class, will you arrive on time?

    How much extra time will you have or how late will you be?

3. Have you ever used a measure of time in place of distance before? Give an example.

Part D: Parallax

Focus on an object in the room. Look at it with one eye, and then the other quickly again and again. Do you notice how it seems to jump from one place to another? This apparent shift in position is called **parallax** and can be used to gather information about the motion of an object.

1. Using a meter stick, ruler, and masking tape, set up the following apparatus.
    a. Tape a ruler, cm side up, to a wall that won't be damaged by the tape.

    b. Put a piece of masking tape at the 20, 40 and 60 cm marks on the meter stick.
    c. One team member should put on goggles and place the 1–cm end of the meter stick at the bridge of their nose. The other end should be at the 1 cm mark on the ruler.

    d. Close your left eye (or cover it) and align a pencil held at the 20cm mark on the meter stick with the 1 cm mark on the ruler. This works best when the pencil is held on the right side of the meter stick.
    e. Now, close your right eye and open your left. Measure how many centimeters the pencil appears to have "jumped" to the right using the increments marked on the ruler. It may be helpful for a lab partner to move their finger along the top edge of the ruler until the pencil aligns with their finger to take this reading.
    f. Repeat with the pencil held at the 40 and 60 cm marks on the meter stick.
    g. Have each lab partner repeat the experiment to get multiple trials and find the average.

2. Record your data in the table below:

Distance of pencil from eye:	Trial 1	Trial 2	Trial 3	Trial 4	Average
20 cm					
40 cm					
60 cm					

3. Now answer the following questions:
   a. Why do you believe the pencil appeared to "jump" positions when you switched eyes?

   b. What is the relationship between the distance from your eye and the size of the "jump"?

   c. What information might astronomers learn about a far away star or galaxy using parallax?

Digging Deeper, cont.

Read pages 12-16 on Your Place in the Universe and complete the following.

Term:	Define and Answer:	Relation to Earth
Solar System-	Define in your own terms	What is our solar system made up of?
Planet-	Define in your own terms	What are planets in order in our solar system?
Astronomer-	Define in your own terms	

11

Star-	Define in your own terms	Because of the Sun's.... It is the...
Galaxy-	Define in your own terms	What galaxy is our solar system a part of?

Units of Measurement. When measuring distances in space, there are several possible units to use.

Unit of Measurement	Description	Distance in km	Best used for
Astronomical unit (AU)			
Light-Year (ly)			
Parsec (pc)			

Power of Ten video to show scale: https://www.youtube.com/watch?v=bhofN1xX6u0

Distances in the Universe

Telescope-

What can interfere with using a telescope to view the stars in space?

Why do we launch telescopes into space rather than keep them on Earth?

Classifications of Galaxies- Galaxies are classified according to their shape. Sketch the general shape for the following types of galaxies:

Spiral Galaxy	Elliptical Galaxy	Irregular Galaxy
		Neither spiral or barred, shape can vary

Describe the shape of the Milky Way galaxy as well as our solar system's position in it.

Universe-

***Parallax-

How do astronomers use parallax to measure the distance to a star?

Small Jump=

Large Jump=

Understanding and Applying

1. How does the Doppler effect allow astronomers to detect the motion of a star or galaxy?

2. What can astronomers infer from the fact that other galaxies are moving away from ours?

What evidence supports this?

3. Explain how the Sun produces energy. What keeps the Sun from blowing apart?

4. Explain in your own words the basic process of planet formation.

5. Even though our universe is expanding, what force keeps planets and stars inside our solar systems from expanding away from each other?

6. Would it be possible for a gas giant to form close to the Sun? Explain your answer.

7. Use your understanding of a light-year and the distances from the Sun shown in Table 1 to calculate how many minutes it takes for sunlight to reach each of the eight planets in the solar system. Then use the unit "light minutes" (how far light travels in one minute) to describe the distances from Earth to each object. Recall that light travels at a rate of 300,000 km/sec.

a. First, how far will light travel in 1 min? (Teacher Demo)

300,000km	_____ sec	____km
1 sec	_____min	1 min

b. How many **minutes** will it take for the Sun's light energy to reach...

Mercury (Teacher Demo):

57,900,000km	1 min	________min
	________km	

Venus:

108,200,000km	1 min	________min
	________km	

Jupiter:

778,400,000km	1 min	________min
	________km	

Saturn:

1,426,700,000km	1 min	________min
	________km	

8. Given the rate that light travels, how many **years** will it take light from the following stars/ galaxies to reach Earth?

a. First, how many km can light travel in 1 year? (365 days= 1 year)

______km	________min	_________hr	_________days	_________km
1 min	________ hr	_________day	________ year	________year

15

b. Time for light (in years) to reach Earth from…

i. Our closest neighboring star, Proxima Centauri (4×10^{13} km)?

ii. The center of our own Milky Way Galaxy, (2.365×10^{17} km)?

iii. The outer edge of our closest neighboring galaxy, the Andromeda Galaxy (2.74×10^{19} km)?

10^0 = 1
10^1 = 10
10^2 = 100
10^3 = 1,000
10^4 = 10,000
10^5 = 100,000
10^6 = 1,000,000 *one million*
10^7 = 10,000,000
10^8 = 100,000,000
10^9 = 1,000,000,000 *one billion*
10^{10} = 10,000,000,000
10^{11} = 100,000,000,000
10^{12} = 1,000,000,000,000 *one trillion*
10^{13} = 10,000,000,000,000
10^{14} = 100,000,000,000,000

iv. The Virgo cluster of galaxies (4.73×10^{20} km)?

c. Why do astronomers not often use kilometers to measure distances in space?

10. In gazing at the stars, it is often said that we are looking back in time. Explain how this is possible.

16

Reflecting on the Section

You observed the change in pitch that occurs with the motion of an object emitting sound. A similar effect occurs with the shift in the wavelength of light emitted by a star or galaxy when it moves relative to Earth. You then ran a model of the universe that demonstrated the movement of galaxies away from each other as the universe expands. Next, you observed a model of the formation of the solar system from a cloud of gas and dust.

You found the distance to the next-nearest star (after the Sun) to Earth in astronomical units, light-years, and parsecs. These distances were compared with the distances to other objects in space, including the Andromeda Galaxy and the Virgo cluster. Although the distances between the Sun and planets are great, you observed that the distances between stars, galaxies, and clusters are far greater. This discovery will help you to describe Earth and its place in the universe.

Think About it Again: Claim + Evidence + Reasoning = Conclusion

Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you explain and answer the question.

What do the movements of stars and galaxies tell astronomers about how the universe formed?

How did the solar system form?

What is the probability that there are planetary systems beyond our own? How do you know?

Learning Targets Post Self Assessment (I can):	U	N	S	E
1. Investigate the current theory about the formation of the universe (Big Bang) and the evidence that supports it. (1.3)				
2.Perform an experiment that explains universal expansion. (1.3)				
3. Compare and contrast how distances are measured in space. (1.1)				

APPENDIX B: MODULE 1 GEOLOG 1.7

Name: ______________________________ Period:__________

Chapter 1: Astronomy
Section 7: The Electromagnetic Spectrum

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What do you see? (Using the image above, please make 2 or more inferences and include the observations that led to that thinking.)
Inference 1: **Supporting Observations** 1. 2. **Inference 2:** **Supporting Observations** 1. 2.
Think About It (Use the information below, the picture above and your prior knowledge to create reasonable answers to the following question.)
The sun releases a wide range of energy. A rainbow only shows you a small portion of this energy as seen in the picture above. Please use the information above and your prior knowledge to answer the questions below. **How could scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?**

1

Investigate

In this series of investigations, you will be exploring the electromagnetic spectrum (arrangement of electromagnetic radiation according to wavelength) in three different ways.

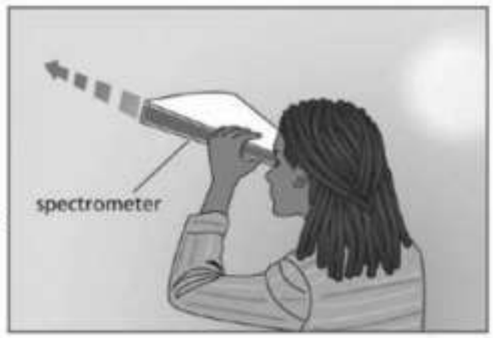
Part A: Observing Part of the Electromagnetic Spectrum

WARNING Do not look directly at a light with the unaided eye. Use the spectrometer as instructed. Never look directly at the Sun. Doing so even briefly can damage your eyes permanently.

1. Obtain a spectrometer similar to the one shown in the illustration. Hold the end with the diffraction grating to your eye. Direct it toward a part of the sky away from the Sun. Look for a spectrum along the side of the spectrometer.

    a) Write down the order of the colors you observed.

    b) Move the spectrometer to the right and left. Record your observations.



2. Look through the spectrometer at a fluorescent light.

    a) Write down the order of the colors you observed.

3. Look through the spectrometer at an incandescent bulb.

    a) Write down the order of the colors you observed.

4. Use your observations to answer the following questions:

    a) How did the colors and the order of the colors differ between reflected sunlight, fluorescent light, and incandescent light? Describe any differences that you noticed.

    b) What if you could use your spectrometer to look at the light from other stars? What do you think it would look like?

5. Your teacher will show you some spectrum tubes that contain only one specific element.

Using your spectrometer, observe each tube when illuminated with a spectrum tube power supply and record what you see. (If you don't have access to this equipment, please see http://astro.u-strasbg.fr/~koppen/discharge/)

Element	Observations

a) Why would these look different than the light from a window or incandescent bulb?

Part B: Using Electromagnetic Radiation in Astronomy—Spectral Analysis

Astronomers use electromagnetic radiation to study objects and events within our solar system and beyond to distant galaxies. In this part of the Investigate, you will create a spectral analyzer to compare the spectral lines (also called a spectral fingerprint) for various stars and determine what that tells us about these stars.

1. Remove the spectral analyzer page found on the last page this geolog.
2. Cut out the pull tab card, the spectral fingerprints card, and stars B, C, and D along the dashed lines. LEAVE THE LABELS ON STARS B, C, AND D SO YOU CAN TELL THEM APART.
3. Make 5 slits along the dashed lines A, B, C, D, and E on the fingerprints card.
4. From left to right, weave "Pull Tab Out" up through slit E, down through slit D, up through C, down through B, and up through slit A.
5. Keeping the sodium doublets aligned, compare the lines of each known element with the lines of Star A. If the lines match, then the element is present. Record your findings in the "chemical composition" column of the data table below.
6. Stars B, C, and D are provided for further study and comparison. Each can be placed over Star A and analyzed.

Star	Chemical Composition	Other Characteristics
A		
B		Standard for comparison
C		
D		

7. Use your spectral analysis data to answer the following questions:
   a) When we say that the neon colored lights look beautiful at night, what color comes to mind?

      What color is suggested by the "fingerprint" of neon?

   b) Did any of the stars have the same chemical composition? If so, which?

   c) Sometimes scientists see spectral lines that do not fit the usual pattern. These lines might be shifted from their usual positions suggesting that the star is moving either toward or away from the observer.
      - A blue shift is a shift in the spectral lines toward the blue end of the spectrum. What does this tell us about the motion of the star?
      - A red shift is a shift in the spectral lines toward the red end of the spectrum. What does this tell us about the motion of the star?
      - Look at the spectral lines for stars B and D. If Star B is the standard for comparison, how is star D different and what does this tell us about Star D?

   d) If the scientist sees lines that are wider than usual, he or she relates this spectral broadening to either rotational speed (the broader the faster), temperature (the broader the hotter), or pressure (the broader the greater the pressure).
      - Look at the spectral lines for Stars B and C. If Star B is the standard for comparison, how is Star C different and what could explain this?

   e) Now fill out the last column of your data table. Think about the stars' color, motion, speed, temperature, and pressure as you do this.

Digging Deeper

Read pages 87-92 in your text on Electromagnetic Radiation. Use the following to organize the information.

I. The Nature of Electromagnetic Radiation (pages 87-88)

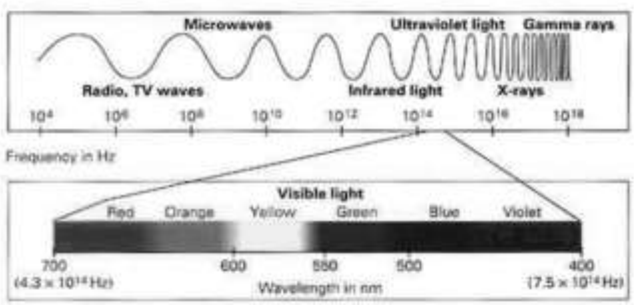
Define the following vocab terms:

electromagnetic radiation:

spectroscopy:

spectrometer:

- Draw and label an arrow above the diagram of the EM Spectrum indicating in what direction energy would increase based on wavelength.



EM Spectrum

(from http://web.princeton.edu/sites/ehs/laserguide/spectrum.jpg)

Finish the phrases by circling the correct term.

- As wavelength decreases, energy decreases increases
- As wavelength increases, energy decreases increases

** II. **Astronomy and the Electromagnetic Spectrum** (pages 88-90)

Tool	How It Works	What It's Used For
Light Telescope		
Radio Telescope		
X-ray Telescope		

III. Using Electromagnetic Radiation to Understand Celestial Objects (pages 90-92)

spectrum-

What are 3 things the spectra of a star can tell us about that star? Explain how/why.

1.
Explain:

2.
Explain:

3.
Explain how this relates to the Doppler effect:

Checking Up (Talk Science)

1. What are the colors of the spectrum of visible sunlight, from longest wavelength to shortest?

2. Which light wavelengths can be more harmful to you than others? Why?

3. What tools do astronomers use to detect different light wavelengths?

4. How can scientists measure the speed of a distant object in space?

Part C: Hubble's Law
In Investigate C, we will review the Doppler *effect with light waves to find a galaxy's velocity.* Since a galaxy is made up of stars, the redshift principles can be applied to the spectra from an *entire galaxy. We will then plot the velocity data on a graph to determine Hubble's Law.*

"How are light waves different from sound waves?"

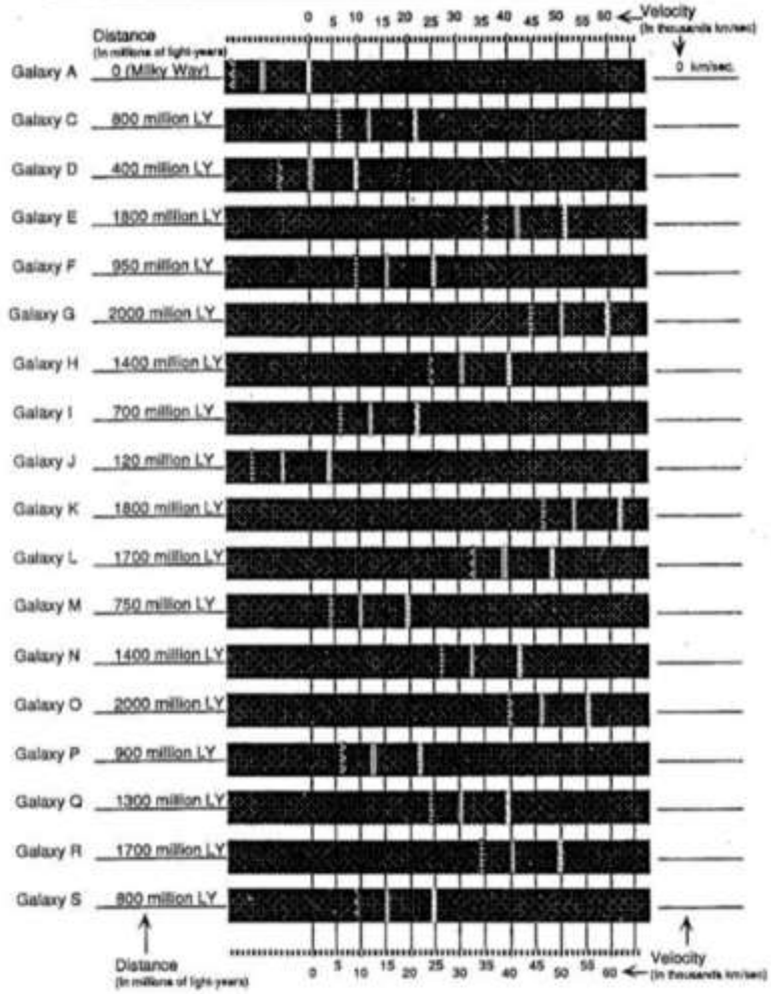
Light waves can exhibit the Doppler effect in a very similar way to the acoustic Doppler effect that we hear. Light waves differ from sound waves by vibrating electric and magnetic fields instead of vibrating air. They move faster than sound: 300,000 km/s as opposed to sound that travels at .3 km/s. The order of the visible spectrum of light is red, orange, yellow, green, blue, violet. If the highest frequency of all light colors is violet, than the lowest frequency color is ____________________. This means that ________________ will have a short wavelength while __________________ will have a long wavelength.

Hydrogen is the most common element in the universe. Nearly all stars have hydrogen. If we look at the spectrum of a star, we nearly always see the red, turquoise, and violet lines associated with hydrogen, along with other lines that are from other elements found in the star. Each color line is a certain frequency of light. Consider the brightest line in the hydrogen spectrum. If a star is moving toward you or away from you, each spectrum line will be shifted either toward the red or toward the violet end of the spectrum because of the Doppler effect. If a star is going away from us, will its spectrum lines shift toward the red end or the violet end of the spectrum? __________

In the following diagram, "Spectra of Fast Moving Galaxies," you will see the hydrogen spectrum lines for several galaxies. The darkest line in the spectrum represents red. The scales at the top and bottom of the sheet relate Doppler shifts of the galaxies' spectra with the velocities of the galaxies. If a positive velocity means the galaxy is moving away from us, what would it mean if the galaxy has a negative velocity? ______________________________ If a *galaxy's spectrum is shifted toward the red end of the spectrum, is the galaxy moving toward us* or away from us? ________________________

1. Calculate how fast each galaxy is moving and write down its velocity in the box by the galaxy. Remember that a positive velocity means the galaxy is moving away.

Spectra of Fast Moving Galaxies



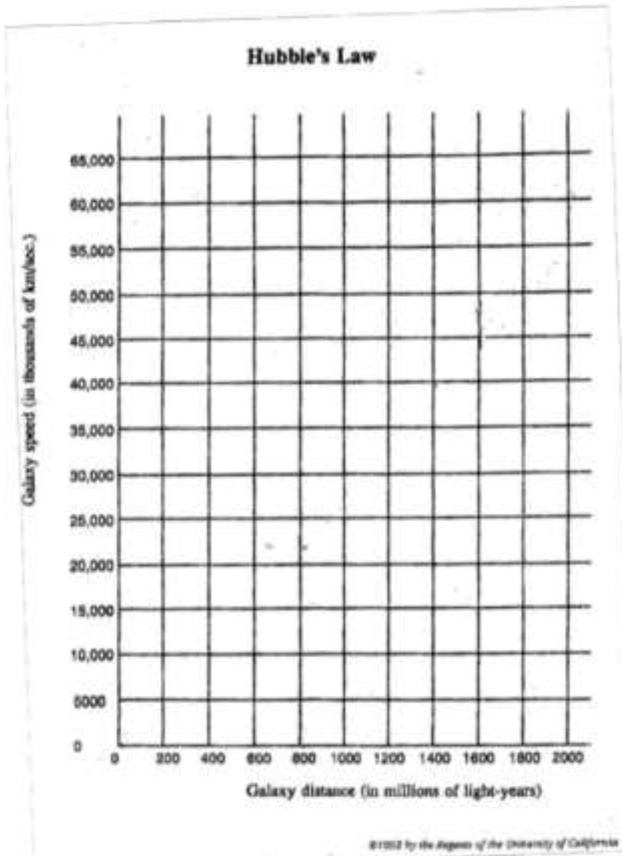
Hubble's Law

Hubble's Law describes the relationship between the distance a galaxy is from us and the velocity as which it is moving away. This law is named in honor of Edwin Hubble, the astronomer who first discovered it. Assuming that Hubble's Law applies for most galaxies, astronomer can use it to estimate distances to the most remote galaxies by measuring redshifts, finding velocities, and calculating distances using Hubble's Law.

2. a) Why are most galaxies moving away from us?

b) Are there any exceptions to this rule? Explain.

3. On the following graph, plot a point for each galaxy's distance and velocity as you determined on the previous page.



a) Include a trend-line and an equation for this trendline. Be sure your equation is in y=mx+b form.

b) What is the numeric value of the slope?

c) What units would this slope have?

d) What does the slope represent?

e) How would you describe in words what the graph tells you?

f) What does Hubble's law imply about how our universe is behaving?

g) How distant is a galaxy that is found to be receding from us at a rate of 120,000 km/s?

Understanding and Applying (Talk Science)

1. Imagine that you are on a distant planet. Name two parts of the electromagnetic spectrum that you would use to investigate Earth. Explain the reasoning for your choices.

2. Refer to Figure 1 in the Digging Deeper (p88) to answer the questions below.

   a) Describe the relationship between wavelength and energy in the electromagnetic spectrum.

b) Based upon this relationship, why do astronomers use X-ray telescopes to study supernova explosions and black holes?

3. The Sun looks yellow, can warm the surface of your skin, and can also give you a bad sunburn. Explain these three everyday phenomena in terms of the electromagnetic spectrum and peak wavelength.

Yellow color-

Warms your skin-

Sunburn-

Reflecting on the Section and the Challenge

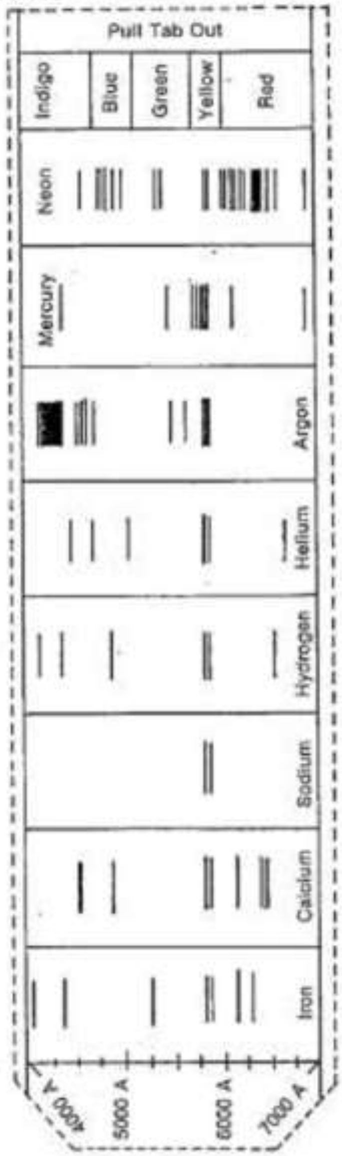
The spectrometer helped you to see that visible light is made up of different color components. Visible light is only one of the components of radiation you receive from the Sun. In the second part of the Investigate, you explored some of the information scientists obtain by looking at the spectra emitted from distant stars. Finally, you used the line spectra for various galaxies to investigate Hubble's Law and the behavior of an expanding universe.

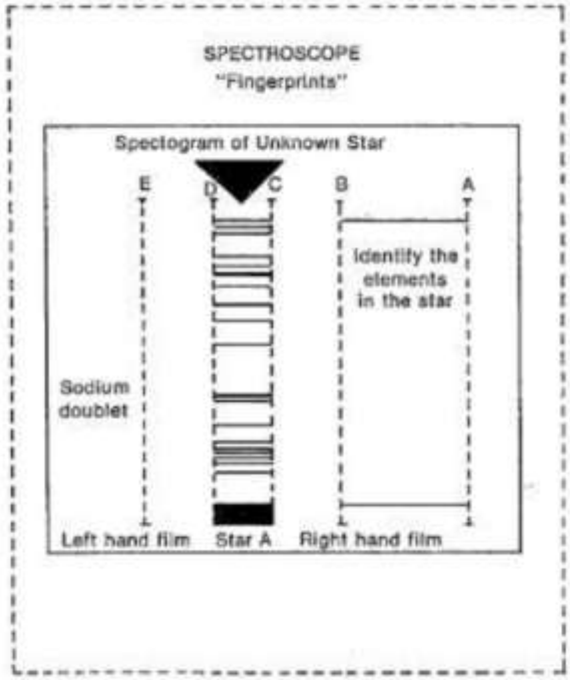
Think About it Again: Claim + Evidence + Reasoning = Conclusion

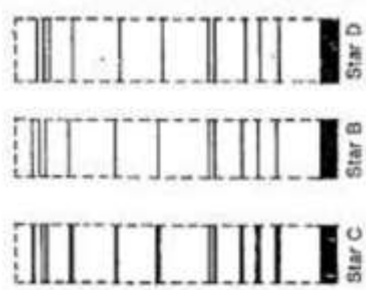
Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you explain and answer the question.

How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?

NAME ______________________ DATE __________ CLASS __________







APPENDIX C: HIGH SCHOOL ANSWER SHEETS

Name: ______________________________ Period: ____________

Chapter 1 Astronomy
Section 3: Origin of the Universe and the Solar System
Section 1: Size and Scale of the Universe
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Think About it Again: Claim + Evidence + Reasoning = Conclusion

Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you *explain* and answer the question.

What do the movements of stars and galaxies tell astronomers about how the universe formed?

Name: ______________________________ Period: ____________

Chapter 1: Astronomy
Section 7: The Electromagnetic Spectrum

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Think About it Again: Claim + Evidence + Reasoning = Conclusion

Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you *explain* and answer the question.

How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?

APPENDIX D: UNIT C ACTIVITY 26

26 Boomtown's Topography

PROBLEM SOLVING

An important part of evaluating a building site is determining the stability of the land. Stable areas have landforms that have not changed much over a long time. One way to learn about recent changes to the land surface is to compare the present day topography with past topography.

Although Boomtown has grown quickly in the last twenty years, it was only a small town one hundred years ago. The Boomtown Library has maps that can show you how the area looked in the past.

CHALLENGE

What can topographical maps tell you about the stability of a building site?

MATERIALS

For each pair of students

1 **Student Sheet 26.1, "Maps of Boomtown 100 Years Ago"**
1 **Student Sheet 26.2, "Maps of Boomtown 20 Years Ago"**
1 **Student Sheet 26.3, "Maps of Boomtown Today"**

PROCEDURE

1. Each student sheet shows a street map and a topographical map of Boomtown at different times: 100 years ago, 20 years ago, and today.
2. In your science notebook, make a table like the one below.
3. Carefully examine the maps and compare one location at a time.

Boomtown through Time

Location	100 years ago	20 years ago	Today
Marsh			
Hillside			
Cliff			

Observe changes in

- roads and buildings
- waterways
- landforms

4. Discuss any changes you see in the maps with your partner. Record your observations in your table.
5. After observing all the maps, discuss your ideas with the other pair in your group of four. Review your table together and add any new observations of the three building sites.

ANALYSIS

1. What is the contour interval in the topographical maps of Boomtown?
2. a. What major changes did you observe between 100 years ago and 20 years ago?

   b. What major changes did you observe between 20 years ago and today?
3. Look at the maps of the three locations in Boomtown.

   a. Which of the three locations is the most stable?

   b. Which of the three locations is the least stable?

   c. Explain the evidence that supports your answers to 3a and 3b above.
4. Do the maps indicate possible problems for building at any of the possible locations?

APPENDIX E: UNIT C ACTIVITY 29

29 Weathering, Erosion, and Deposition

READING

Earth processes are dynamic actions that occur both on the earth's surface and inside the earth. Any process that breaks down earth material, such as water eroding the side of a hill, is called a **destructive** process. Processes that build up earth material, such as the deposition of sediments that create landforms such as deltas, are called **constructive** processes.

Destructive forces are not always harmful and constructive forces are not always helpful. The effect of natural earth processes depends on the situation. Before building, it helps to understand how certain earth processes affect the land you plan to build on.

CHALLENGE

What happens when soil and rocks are moved from one place to another?

MATERIALS

For each student

1 **Student Sheet 29.1, "Three-Level Reading Guide: Weathering, Erosion, and Deposition"**

Destructive earth processes helped form these towers of rock, called hoodoos, in Arches National Park.

In Alaska, where this river meets a lake, constructive earth forces built up a delta.

C-22

READING

Use Student Sheet 29.1, "Three-Level Reading Guide: Weathering, Erosion, and Deposition," to guide you as you complete the following reading.

The Process of Weathering

One earth process that breaks down rocks into smaller pieces is called **weathering.** Over time, rocks crack, crumble, and are broken apart by water and wind. Drops of water on a rock may repeatedly freeze and melt, causing the rock to crack. Water may react with some of the chemicals in a rock and cause part of the rock to break down. Rocks sometimes fall from higher places, breaking as they fall. Small animals and the roots of plants also contribute to the weathering of rock when they burrow into the ground. Weathering forms sediments that can be moved by wind and water.

The Process of Erosion

The movement of sediments from one place to another by water, wind, or ice is called **erosion** (e-ROW-shun). When water erodes the earth's surface, it cuts into the ground, forming surface channels. These channels can range from tiny depressions in the earth to huge canyons, such as the Grand Canyon. Slow and steady water erosion over long periods of time has created valuable features of the earth's landscape such as lakes, rivers, hills, canyons, and fertile plains.

Natural events, such as the floods from storms and tsunamis, often cause more dramatic erosion. Shorelines have shifted and rivers have changed their courses as a result of these events. Glaciers—large sheets of snow and ice—also bring erosion. The glacier's weight causes it to move slowly, scraping away the surface of land.

This house was destroyed when the land under it collapsed.

Results of Erosion

Erosion forms important landforms, but it can also be damaging. Serious problems occur when land quickly collapses or slides near buildings or roads, as shown at left. Slower erosion can also cause damage to roads and buildings. A hillside that erodes over many years can cause buildings on it to shift or be in danger of toppling over. Erosion near a road can cause rocks and sediments to suddenly move onto the road. Even worse, the road itself could eventually erode.

Erosion also creates caves. Ocean waves that crash into sandstone or limestone wear pockets of the rock away. Other caves are caused by rainwater that seeps into the earth. Rainwater picks up carbon dioxide from decaying plants and animals, forming a weak acid. This acid dissolves limestone, forming a cave. As the carbon dioxide evaporates, calcium carbonate leaves cone-shaped structures that hang from the roof (stalactites) or project from the floor (stalagmites) of the cave.

Glaciers caused these landforms in Yosemite National Park.

The projections from the roof (stalactites) and floor (stalagmites) in this cave formed from calcium carbonate left behind when carbon dioxide evaporated from the cave.

The Process of Deposition

When erosion carries sediments from one place to another, the sediments are left, or *deposited* somewhere else. This earth process is called **deposition** (de-puh-ZI-shun). It occurs when pieces of rock or soil settle out of flowing water, ice, or wind as they slow down. The rocks and earth materials that a glacier picks up are often deposited far away from their source. The processes of erosion and deposition are closely related because erosion moves the sediments that are eventually deposited. A delta at the mouth of a river is an example of a landform formed by deposition.

In some cases, deposited sediments can be helpful. For example, sediments add important nutrients to the soil. The Mississippi and Nile River valleys have large fertile **floodplains** that are excellent for growing crops. These plains have been formed by the deposition of sediments that occurs when the rivers flood. After very long periods of time, deposited sediments can even form rocks such as sandstone. Deposition also builds landforms in new places. Figure 1 below shows the amount of sediment at the mouths of rivers in different areas of the U.S. Notice the large amount of sediment where the Mississippi River empties into the Gulf of Mexico.

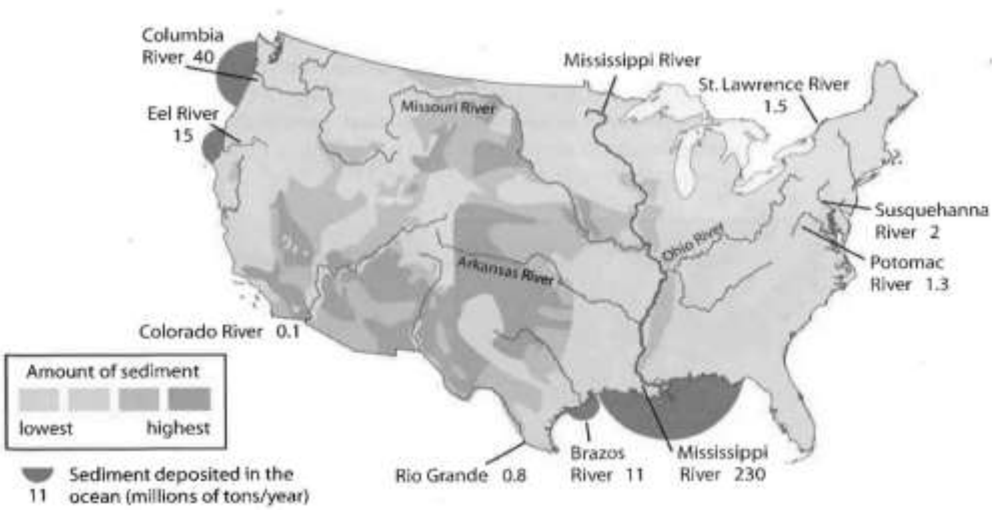

FIGURE 1: SEDIMENT DEPOSITION IN THE UNITED STATES

The size of each brown semicircle indicates the amount of sediment deposited by a river when it empties into the ocean. Darker colors on the land indicate eroded sediments that will be moved by rivers.

Sediments have filled up the opening of this drainage pipe that empties a stream into a lake.

In other cases, deposited sediments can be harmful. Sediments can build up and fill in rivers, lakes, wetlands, bays, and even parts of the ocean. Sediments can cover the habitat areas needed by fish and other animals. For people, deposition in the wrong place can make the water too shallow for boats and clog the pipes that provide water to towns and cities.

People and Earth Processes

The processes of weathering, erosion, and deposition have been occurring for billions of years. Many natural factors affect the rate of these processes. In addition, human activities can accelerate them. For example, the photos below show that clearing plants from the land can result in erosion or deposition. Construction and farming are the two human activities that cause the most erosion. These activities break apart the rocks, soil, and plant roots that hold the land in place. This makes it easier for water or wind to erode the exposed land. In time, the effects of such erosion can make such areas less suitable for building or farming.

Once sediments have been eroded as a result of human actions, they can cause problems when they are deposited. Many rivers, lakes, and ocean areas have been filled in by heavy deposition. In addition, sediments can carry pollution when they are deposited. These sediments can carry toxic materials, such as pesticides used in farming or chemicals that are already present in the soil.

In this suburban neighborhood, sediments were washed into the street by the rain, because the soil was not protected during house construction.

On this farm, rains have damaged crops by eroding soil from one place and depositing it in another location.

ANALYSIS

1. Why is weathering important to the process of erosion?
2. Why does erosion always lead to deposition? Explain and provide an example.
3. Prepare a concept map for weathering, erosion and deposition. Be sure to use the following terms:

earth processes	weathering	erosion
deposition	sediments	wind
water	ice	floodplains
lakes	toxic materials	environment
delta	water	positive effects
negative effects	farming	construction

4. Look back at the topographical maps on the student sheets from Activity 26, "Boomtown's Topography." Choose one major topographical change in Boomtown. Describe the change and the earth process(es) that may have caused the change.
5. At which of the three building sites—Delta Marsh, Green Hill, and Seaside Cliff—would you expect:
   a. erosion to have the most effect on the land?
   b. deposition to have the most effect on the land?

EXTENSION

Earth processes such as weathering, erosion, and deposition help make the landforms that are all around you. Some landforms are formed quickly, while others take millions of years. Visit the *Issues and Earth Science* page of the SEPUP website to find more information about specific landforms found in the United States.

APPENDIX F: MIDDLE SCHOOL ANSWER SHEETS

Name: ______________________________ Period: ____________

Chapter 1 Astronomy
Section 3: Origin of the Universe and the Solar System
Section 1: Size and Scale of the Universe
Adapted from EarthComm, Second Edition, ©2012

Think About it Again: Claim + Evidence + Reasoning = Conclusion

Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you *explain* and answer the question.

What do the movements of stars and galaxies tell astronomers about how the universe formed?

Name: ______________________________ Period: ____________

Chapter 1: Astronomy
Section 7: The Electromagnetic Spectrum
Adapted from EarthComm, Second Edition, ©2012

Think About it Again: Claim + Evidence + Reasoning = Conclusion

Make a claim (a statement that you believe is true) when answering the question, use evidence from this section as well as sharing your reasoning (justification) as you *explain* and answer the question.

How do scientists use electromagnetic radiation to obtain evidence about the behavior of our universe?

APPENDIX G: TALK SCIENCE CHECKLIST AND HANDOUT

Checklist

Goals for Productive Discussions and Nine Talk Moves

Talk Science in the Inquiry Project

Goal One Help Individual Students Share, Expand and Clarify Their Own Thinking	Notes/Frequency of Use
☐ **1. Time to Think** - Partner Talk - Writing as Think Time - Wait Time	
☐ **2. Say More:** "Can you say more about that?" "What do you mean by that?" "Can you give an example?"	
☐ **3. So, Are You Saying...?:** "So, let me see if I've got what you're saying. Are you saying....?" (always leaving space for the original student to agree or disagree and say more)	
Goal Two Help Students Listen Carefully to One Another	
☐ **4. Who Can Rephrase or Repeat?** "Who can repeat what Javon just said or put it into their own words?" (After a partner talk) "What did your partner say?"	
Goal Three Help Students Deepen Their Reasoning	
☐ **5. Asking for Evidence or Reasoning** "Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?"	
☐ **6. Challenge or Counterexample** "Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?	
Goal Four Help Students Think With Others	
☐ **7. Agree/Disagree and Why?** "Do you agree/disagree? (And why?)" "What do people think about what Ian said?" "Does anyone want to respond to that idea?"	
☐ **8. Add On:** "Who can add onto the idea that Jamal is building?" "Can anyone take that suggestion and push it a little further?"	
☐ **9. Explaining What Someone Else Means** "Who can explain what Aisha means when she says that?" "Who thinks they could explain why Simon came up with that answer?" "Why do you think he said that?"	

TERC

The Inquiry Project: Bridging Research & Practice
Supported by the National Science Foundation

Adapted from: Chapin, S. O'Connor, C., & Anderson, N., (2009). *Classroom Discussions: Using Math Talk to Help Students Learn, Grades 1-6.* Sausalito, CA: Math Solutions Publication

Tips for a Good Discussion:

Think Thoroughly

- Do you need to write down your thoughts?
- Can you explain your ideas?
- Can you give an example?

Listen Carefully

- Do you know what your classmate said?
- Can you reword what your classmate said?

Ask for More

- Why does your classmate think that?
- How did they come to that conclusion?
- What if something was different?

Develop Ideas

- Do you agree or disagree with your classmate?
- Can you explain what your classmate said?
- Can you add more information to something your classmate said?

APPENDIX H: DISCUSSION REFLECTION SHEETS

Name: ______________________________ Period: _____________

Chapter 1: Astronomy
Section 7: The Electromagnetic Spectrum
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How would a discussion help you write your answer?

Name: ______________________________ Period: ____________

Chapter 1: Astronomy
Section 7: The Electromagnetic Spectrum

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How did your discussion help you write your answer?

Name: ______________________________ Class: _____________

Unit C Erosion and Deposition

Activity 29: Weathering, Erosion, and Deposition

How would a discussion help you write your answer?

Name: ______________________________ Class: _____________

Unit C Erosion and Deposition

Activity 29: Weathering, Erosion, and Deposition

How did your discussion help you write your answer?

APPENDIX I: TEACHER QUESTIONNAIRE

1. How do you teach your students to use the Claim, Evidence, Reasoning framework? Methods, steps, etc.

2. How often do you use Talk Science in your classroom?

3. Do you teach your students how to use the Talk Moves to talk to each other? If so, how do you teach this skill?

4. What did your classroom look like during the “traditional” discussion? Arrangement of seats, your position, etc.

5. What did your classroom look like during the Talk Science discussion? Arrangement of seats, your position, etc.

6. What were your thoughts about this study? Things you liked, would change, etc.

7. Would you be interested in collecting more data in your classroom?

8. Do you have any thoughts about the rubric? Grade-appropriateness, clarity, etc.

APPENDIX J: RUBRIC AND REFLECTION SCORES OF HIGH SCHOOL STUDENTS

		Question 1				Question 2				
	Student Identifier	Claim	Evidence	Reasoning	Content	Claim	Evidence	Reasoning	Content	Discussion Reflection
No Discussion	A01	1	1	1	1					
	A04	3	1	1	2	1	1	1	1	3
	A10	2	1	1	1	3	1	1	2	
	A16	3	1	1	2					
	A17	3	2	3	3	1	1	1	1	1*
	A22	1	1	1	1	3	1	1	2	4
	A24	1	1	1	2					
	A28					2	1	1	1	3
	A29					1	1	1	1	2
	A30					1	1	1	1	4
Discussion without Talk Science	A06	2	1	1	1	3	1	1	2	4
	A07	3	2	2	2	4	2	2	3	3
	A12	2	1	1	1	3	1	1	2	1*
	A13	2	1	1	2	1	1	1	1	4
	A15	4	3	3	3					
	A25	3	2	1	2	3	1	1	2	1
	A26	3	2	3	3	4	2	1	3	3
	A27	3	3	2	3	3	1	1	2	3
	A31					2	1	1	1	

		Question 1				Question 2				
	Student Identifier	Claim	Evidence	Reasoning	Content	Claim	Evidence	Reasoning	Content	Discussion Reflection
Discussion with Talk Science	A02	3	2	1	2					
	A03	3	1	1	2	3	2	2	3	3
	A05	3	2	1	2	1	1	1	2	2
	A08	4	1	1	2	3	2	2	3	4
	A09	2	2	1	2	3	2	2	3	4
	A11	3	1	1	1	3	2	3	3	4*
	A14	2	1	1	1	1	1	1	1	4*
	A18	3	1	2	2	3	3	2	3	3
	A19	1	1	1	1	3	2	1	2	3
	A20	3	2	1	2	3	2	1	2	4
	A21	4	1	1	3	2	2	3	3	2
	A23	3	2	2	2	3	2	2	3	4
	A32					1	1	1	1	3
	A33					2	2	3	3	

APPENDIX K: RUBRIC AND REFLECTION SCORES OF MIDDLE SCHOOL STUDENTS

		Question 1				Question 2				
	Student Identifier	Claim	Evidence	Reasoning	Content	Claim	Evidence	Reasoning	Content	Discussion Reflection
No Discussion	J05	3	1	1	2	4	1	1	2	2
	J08	3	1	1	1	3	1	1	1	3
	J14	3	1	1	1	2	1	1	1	4
	J17	3	2	1	2	4	1	1	2	4
	J22	3	1	1	1	4	1	1	3	4
	J24	1	1	1	1	2	1	1	1	3
	J26	3	1	1	1	4	1	1	2	4
	J29	2	3	1	1	4	3	1	3	4
	J30	3	1	1	1	4	1	1	2	4
	J32					1	1	1	1	3
	J34	3	1	1	1	1	2	1	2	4
	J35					4	1	1	3	4
	J37					4	1	1	3	3
	J40	4	2	2	2	4	1	1	3	4
	J48	1	1	1	1	3	3	2	3	3
	J54	1	1	1	1	4	1	1	1	4*
	J55	3	1	1	1	1	1	1	1	4
	J60	2	1	1	1	1	1	1	1	3
	J61					1	1	1	1	3
Discussion without Talk Science	J04	3	2	3	2	3	1	1	2	2
	J06	3	2	1	1	3	1	1	1	4
	J09					1	1	1	1	1
	J10	4	3	4	3	3	1	1	1	2

	Student Identifier	Question 1 Claim	Question 1 Evidence	Question 1 Reasoning	Question 1 Content	Question 2 Claim	Question 2 Evidence	Question 2 Reasoning	Question 2 Content	Discussion Reflection
Discussion without Talk Science	J15					3	1	1	1	1
	J16					1	1	1	1	4
	J18					3	2	1	1	4
	J19	3	1	1	1	4	1	1	2	3
	J21	2	3	1	1					3
	J23	3	1	1	1	3	1	1	2	1*
	J25					3	1	1	1	1*
	J31					3	1	1	2	3
	J42	3	3	2	2	3	1	1	1	4
	J43	4	2	1	2	3	1	1	1	4*
	J46	3	2	2	2	1	3	2	2	4
	J49	3	2	1	2					
	J51	1	1	1	1					
	J52	3	1	1	1	3	2	2	2	4
	J53					1	1	1	1	1
	J56					4	1	1	2	2
	J62	3	2	2	3	3	2	3	3	4
Discussion with Talk Science	J01	2	2	1	2	3	2	3	3	4
	J02	3	2	2	2	3	2	1	2	2
	J03	4	1	1	2	3	1	1	1	3
	J07	3	3	4	4	3	3	3	3	1*
	J11	1	1	1	1	4	1	1	2	3
	J12	4	2	1	3	4	1	1	2	4
	J13					3	1	1	1	3
	J20	3	2	3	3	4	1	1	1	4
	J27	2	1	1	1					

	Student Identifier	Question 1 Claim	Question 1 Evidence	Question 1 Reasoning	Question 1 Content	Question 2 Claim	Question 2 Evidence	Question 2 Reasoning	Question 2 Content	Discussion Reflection
Discussion with Talk Science	J33	2	3	1	2	3	1	1	3	4
	J36	3	1	1	2	4	1	1	1	2
	J38	3	2	1	2	3	3	1	3	4*
	J39					4	1	1	1	3
	J41					1	1	1	1	3
	J44	2	1	1	1	3	1	1	1	3
	J45	4	1	1	2	4	1	1	2	4*
	J47	1	1	1	1					
	J50					4	1	1	1	1
	J57	4	1	1	2	3	2	2	3	4
	J58	3	3	1	4	3	2	3	3	2
	J59	1	1	1	1	2	1	1	1	3*

BIOGRAPHY OF THE AUTHOR

Rachel A. Martin was born in Peoria, Illinois on July 7, 1987. She was raised in Creve Coeur, Illinois and graduated from East Peoria Community High School in 2005. She attended Illinois Wesleyan University and graduated in 2009 with a bachelor's degree in biology with a minor in psychology. She attended East Tennessee State University and graduated in 2013 with a master's degree in geosciences. She is a candidate for the Master of Science degree in Teaching from The University of Maine in August 2016.