Middle School Students' Opportunities for Integration in a Next Generation Science Standards Focused Curricular Unit

by

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Dedication

For All the Teachers Who Supported Me Along the Way…

Most Importantly, Malcolm and Martha Fick

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Chapter 1
Introduction

The United States was founded on principles of national governance but local control. As a result, efforts to create national standards have been stymied, leaving us with the development of national recommendations for state standards as a solution. The first set of recommended standards, the National Science Education Standards (National Research Council 1996), ultimately became the foundation for the state standards of most states. Over time, the science education community became dismayed that this initial document did not provide enough guidance for how curriculum and assessment might be developed to promote science learning, and for the selection of big ideas and science practices that might guide students' development.

When the National Science Education Standards were published in 1996, one chapter was dedicated to science content standards (National Research Council, 1996; Chapter 6), and it included both science content and inquiry standards. The "science as inquiry" standards included a list of science practices that are important to the development of science knowledge, but little if any guidance about how those should be combined with science content in a classroom. In fact, the way they were presented could lead one to believe that content and inquiry should be taught separately. How these inquiry principles might be applied was left open to interpretation. As a result, the term "inquiry" was applied very liberally and loosely, giving the word less power in describing effective science teaching.

The recent national recommendations for standards and practice in science education, outlined in the National Research Council's *Framework for K-12 Science Education* (National Research Council, 2012), emphasize the importance of instruction to promote students' learning of science content and practices together to "cultivate scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context… developing students' knowledge of the content of science and the emphasis placed on scientific practices" (National Research Council, 2012, p. 41). Both the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) and the *Framework* focus on instruction based on the integration of three dimensions of science education: disciplinary core ideas, science and engineering practices, and crosscutting concepts. Together, the disciplinary core ideas and crosscutting concepts represent the big ideas of the science content, which should be learned through the practices of science and engineering. Each of the standards integrates the three dimensions of science education into a single integrated standard statement. However, the field of science education has yet to fully describe what integration would look like, leaving teachers to figure this out on their own.

Significant research has focused on teaching and learning associated with two of the dimensions of science education, disciplinary core ideas and science practices. For example, curricular units have been developed to support students' use of the science practice of scientific explanation in their learning of the disciplinary core ideas related to ecological processes and relationships (Songer, 2006). Another line of research has examined curricular units to support students' use of the science practice of modeling to develop their understanding related to disciplinary core ideas about how the elbow functions (Lehrer & Schauble, 2000). These research lines, and others, focused on how to support students in their development of science practice in the context of disciplinary core ideas. However, the way that crosscutting concepts, the big themes of science, are or could be integrated with the disciplinary core ideas and science practices remains unstudied. Crosscutting concepts have long been considered an important part of instruction but one that curriculum developers have struggled to make apparent (Krajcik et al., 2008). The intention of including crosscutting concepts in the three dimensions is for standards and instruction to be explicit about the connections across science concepts and disciplines (National Research Council, 2012).

Although the three dimensions are the major focus of the standards, standards developers (National Research Council, 2012) identify the need for clear examples of what integration of the three dimensions looks like in curriculum and instruction; this concern is echoed in organizational responses to the publication of the *NGSS* (National Science Teachers Association, 2013; Carlson et al., 2013). The standards and supporting materials lack examples of how students are expected to integrate the described knowledge, and how teachers should approach fostering that integration. To support the work of both students and teachers, we need a clear understanding of what the results should look like.

This research was intended to describe the opportunities for integration that occurred in a curricular unit designed to promote students' integration of the three dimensions of science education. The overall research question for this study was the following:

> *What does integration of the three dimensions of science education look like in a middle-school science classroom?*

This study focuses on a single science teacher enacting a middle school science curricular unit developed in collaboration with the teacher, with the intention of integrating the three dimensions of science education as specified by an *NGSS* standard. This study focuses on (1) the opportunities to integrate the three dimensions present in the enacted curriculum, and (2) any changes in students' understandings related to the standard as represented in their models, explanations, and interviews. Chapter 2 presents the literature that serves as a foundation for this study, including research related to the individual dimensions being integrated, the curriculum design principles used in the development of the curricular unit, and the theory of student learning that served as a basis for the development of activities. Chapter 3 describes the design of the research study including the context, participants, data collected, and the analysis methods used. Chapter 4 presents some examples of opportunities to learn and students' understandings associated with those opportunities. These findings support the development of a description of what integrated instruction looks like in a classroom. Chapter 5 concludes by presenting the results in the context of the literature, proposing implications for the findings and future lines of research related to the integration of the dimensions of science education.

Chapter 2
Literature Review

Introduction to Science Education Reform

The change in the millennium brought a new national education policy, which required all students to have state education standards to which they would be held accountable. Each state was responsible for generating its own standards and its own level to which it would be held accountable. The results were a wide variety in educational goals for students. In the discipline of science, students have not been held accountable to learning as measured by state assessments on a national level, but teachers are held accountable to teaching the standards on a school, local, or state policy level. Many states built their standards using the *National Science Education Standards* (*NSES*; National Research Council, 1996), a national recommendation for science standards, but the standards were found to be too numerous and not specific enough. In response, science education specialists on the state, local, and national levels joined together to develop a set of new standard recommendations. These new standards, the *Next Generation Science Standards* (*NGSS*; NGSS Lead States, 2013), are more specific and focus on fewer standards, concentrating on the big ideas of science. They focus on the development of science content knowledge and practices over time, building on students' prior knowledge and experiences.

In the *NGSS*, the content and practices of science education extend across three dimensions: science practices (SPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs). Here, the science practices are considered to be what students and scientists do to develop new knowledge. The eight science practices include asking questions, developing and using models, and scientific explanation. Together, the crosscutting concepts and disciplinary core ideas are considered the science content. As presented in the *NGSS*, the crosscutting concepts are different from the disciplinary core ideas in terms of the type of knowledge conveyed. The disciplinary core ideas are the big ideas of the science content. Disciplinary core ideas focus on the processes and interactions that make up the four disciplines of science: Life Science, Earth and Space Science, Physical Science, and Engineering Science. Crosscutting concepts are the broad themes of science that cut across disciplinary core ideas. These themes are intended to support students in making connections across science disciplines, and to support deeper understanding of science content. The *NGSS* are made up of standards statements, called performance expectations, that are a blend of one science practice, one disciplinary core idea, and one crosscutting concept. These statements are intended to be what students are assessed on, but it is hoped that a curricular unit addressing the standards will include more than one science practice and crosscutting concept, and that they will link together multiple performance expectations focused on a theme in the crosscutting concepts or disciplinary core ideas.

Learning Theory

This research is based on the development of a curricular unit focused on one particular *NGSS* performance expectation. It views learning as a process in which students use prior knowledge, skills, and experiences as a foundation for building new knowledge while working in groups, and that new knowledge is reinforced through the use of metacognitive strategies. The following sections describe the research base about student learning using curriculum materials, on which the development of the curricular unit was based.

Student Learning

In reform-based views of science teaching, instruction is based on a mix of classroom formats including full class discussion, small group work, and individual work. It is generally agreed that students learn best through experiences with the phenomenon, and these experiences are structured so that students build knowledge the way a practicing scientist might (National Research Council, 2005; National Research Council, 2007; National Research Council, 2012).

Students' learning is based on the construction of knowledge, always built on their prior knowledge (Piaget & Inhelder, 1969/2000), using tools and resources to assist them (Vygotsky 1978). Tools can take many forms, including representations of data used for analysis, worksheets that scaffold students' scientific explanations, and models that reflect and expand students' understanding of how a watershed or landscape interacts with water. In the work of both Vygotsky (1978), the role of others was central to their theory of learning, and it was through the development of knowledge as a group that individuals gained a deeper, more nuanced understanding of the concept. This kind of group thinking and development of knowledge can occur while working in small groups, or by engaging in a full class discussion. For example, classroom discussion in which students and teacher engage in a dialogue about the clarification of science content based on shared experiences gives students an opportunity to synthesize their understanding of the concept.

Studies have suggested the dimensions of learning that students might consider to more effectively incorporate and retain new information (Brown, Campione, & Day, 1981). It has also been shown that supporting students to develop knowledge of their own learning and understanding can lead to longer-lasting knowledge and ability (Palincsar & Brown, 1984; White & Frederiksen, 1998). Researchers have studied the effect of the inclusion of various types of prompts to support students' reflection on their own learning (Davis, 2003). Curricular prompts included with the intention of prompting students' reflection on their own understanding fall into a group of supports that are here called metacognitive elements. Metacognitive elements have been shown to promote students' long-term retention of material and the connections they made during a learning experience (White & Frederiksen, 1998). Examples of metacognitive elements are prompts for students to explain how their understanding has changed (Quintana et al., 2004; White & Frederiksen, 1998), and revisiting the same task after having had additional learning experiences (Lehrer & Schauble, 2006; White & Frederiksen, 1998). It has been found that general prompts, rather than prompts specific to the context, were more likely to promote students' metacognition (Davis, 2003).

Curriculum to Support Learning and Instruction

Curriculum to Support Students' Learning

Curriculum materials are generally considered a valuable tool for supporting students' learning. They are intended to support students' learning by providing teachers with a framework on which to establish their enacted instruction. Curriculum designers incorporate a variety of features into the design of the curriculum to support students' learning. Studies have shown that the ways that teachers use the curriculum materials influences what students learn. For example, Songer and colleagues (Songer, Kelcey, & Gotwals, 2009) showed that student learning was correlated with the percentage of the reform-based curriculum that the instructor completed in class. Other studies have shown that the ways that teachers modify the intended curriculum also changes what learning occurs (Fogleman, McNeill, & Krajcik, 2011). To this end, significant research has focused on the ways in which teachers use curriculum materials to support their instruction, and how this influences student learning. To support the enactment of standards-based curriculum, teachers need strong curriculum materials with clear features apparent to the teacher.

Research has looked at the more effective features used by various curriculum materials, and criteria for evaluating the materials have been developed. In particular, the American Association for the Advancement of Science criteria (AAAS Project 2061 2002) were used by Kesidou and Rosemen for the evaluation of curriculum materials (Kesidou & Roseman, 2002). Similarly, Stein, Remillard, and Smith (Stein, Remillard, & Smith, 2007) examined how curriculum materials affect student learning; their findings included descriptions of the ways that curriculum varied and how that variation affected student learning. They were careful to say that no curriculum is self-enacting, and that the standards-based curriculum was challenging to enact, but nevertheless the features of the curricula are correlated with variation in student learning. Here, some of the design principles that recur in a variety of programs are highlighted.

Features of Curricula to Support Learning

Alignment to the Standard

Research supports beginning curriculum development by envisioning the goal for students' learning. Wiggins and McTighe (Wiggins & McTighe, 2005) suggested that curriculum development should begin with the learning goal. In most American teaching contexts, this goal is a state standard. Krajcik and colleagues (2008) suggested that the standards are never as straightforward as they initially appear, and that they require a certain amount of unpacking to determine what the phenomena under study are and how they might be approached. Krajcik (2008) described the unpacking as a process of understanding the phenomena under study, and conceptualizing which science practice or practices might support students' learning of that content. Combining the science content with the science practice into a single statement is the final step in developing one of Krajcik's learning performances (2008). Although the performance expectations in the *NGSS* already strongly resemble the learning performances described by Krajcik, a certain amount of unpacking seems to be necessary to describe the curriculum. For example, one *NGSS* performance expectation in particular focuses on the cycling of water in Earth's systems. The performance expectation could be interpreted in a number of ways, but one thought might be the water cycle. Conceptualized narrowly, the water cycle entails the evaporation, condensation, and precipitation cycle that moves water through the atmosphere and around on the surface of the Earth. Conceptualized more broadly, the water is absorbed into the surface layers, or runs along the surface of the Earth, and then gathers in larger bodies of water. Although the standard already marries the science content with a science practice, this is only the beginning of designing a program in which students can begin to learn in alignment with the performance expectation. Once the science practice has been chosen, supporting activities can be developed with a focus on activities that provide students with clear examples of the phenomenon and that create a clear content storyline (Krajcik, McNeill, & Reiser, 2008).

Clear Content Storyline

One component of curriculum coherence and alignment has been described as a clear content storyline. A clear content storyline is the connectivity between activities that makes the goal and connection between activities and science content apparent to the students (Krajcik et al., 2008; Roth et al., 2011; Roseman, Linn, & Koppal, 2008). This feature supports students' learning by making the continuity between activities apparent, and the process by which the knowledge is being constructed more authentic. Some authors have associated a clear content story line with problem-based learning, where students are engaged in solving an authentic question of the discipline of science (Krajcik et al., 2008; Roseman et al., 2008). In problem-based learning, students are engaged with solving a scientific question. To do so, they use investigations and knowledge-building activities in the science classroom.

4Es + S Framework and Learning Cycle

Assuming that the goal of the learning experience is for students to authentically engage in scientific knowledge construction, it is possible to see the importance of engaging a students' prior knowledge and understanding to build a more complete understanding of the scientific phenomenon being studied. One method for engaging students' prior knowledge and incorporating that knowledge into learning the new phenomenon is through a curriculum structure such as the one developed by Karplus (1977), and modified by Songer (2006), among other researchers. Songer's version of the learning cycle (Songer 2006) involves engaging students' prior knowledge with hands-on investigations and then extending that knowledge to other contexts. In Songer's version, the curricular unit starts with a contextualizing component in which students' prior experience with and understanding of the current material is characterized to frame the subsequent learning opportunities (Engage); in a subsequent lesson, students work with various scientific experiences to experiment with the phenomenon and collect quantitative or qualitative data related to the phenomenon (Explore); they then use the data they collected to observe patterns and make sense of their observation (Explain); and, finally, the curricular unit concludes the lesson by synthesizing the students' knowledge through the development of scientific explanations (Synthesis). An important difference between this learning cycle and others is that this one is not seen as a linear process: A unit may have multiples of any element. Finally, the synthesis components can serve as a formative assessment or as a synthesis of students' knowledge. These are check-in points during the unit, and at the conclusion of the unit, they can be used to monitor students' progress.

Supports and Scaffolds for Supporting Students' Metacognition

The development of metacognition is one approach considered to support students in learning the content and practices of science. White and Frederiksen (1998) developed curriculum materials to support students' metacognitive processes in their work with physics content. White and Frederiksen used a process of reflective self-assessment, meaning that students reflect on their own learning and improvement through a process of self-evaluation. Students made modifications to their conceptual models as their understanding of the phenomena changed over time, and they were encouraged to reflect on their own thinking and learning related to the science concept. In her work with elementary school students, Metz (2000) described one component of metacognitive awareness as knowledge of students' own understanding, promoting students to question what they know and what they do not know about the phenomena under study. This research described metacognitive knowledge as self-regulation and awareness of the limits of one's understanding (Metz 2000).

One approach to developing students' metacognitive reflection is the use of supports or scaffolds in curricular materials. Supports are elements of a curriculum that are intended to draw students' attention to knowledge, practices, or skills that are challenging for students, supporting them to accomplish a task that would be out of their reach without support. Scaffolds are a type of support that is intended to last for only a short period of time (Wood, Bruner, & Ross, 1976), after which they are intentionally faded from the curriculum, slowly moving the task to the student's responsibility. Scaffolding builds on Vygotsky's (1978) zone of proximal development, providing students with assistance to achieve beyond their unassisted capabilities, until they are ready to do the task without assistance.

Although students' reflection on their thinking and learning has been found to be productive in the learning process, many different aspects of metacognition are challenging for students (Bransford, Brown, & Cocking, 2000). In their work developing technological scaffolds for students' science learning, Quintana and colleagues (Quintana et al., 2004) focused on developing supports for productive planning, productive monitoring, articulation during sense-making, and highlighting epistemic features of scientific practices and products. White and Frederiksen (1998) used a learning cycle that progressively provided students with less support as they completed cycles. The cycle supported students in carrying out investigations, as well as their reflection on the process, by using the same stages (question, predict, experiment, model, and apply) through multiple units in the curriculum. Lehrer and Schauble (2006), in their work with elementary school students, created physical models of elbows. Initially, the students focused on creating a physical model that resembled an elbow. Over time, as their attention was refocused on other aspects of the joint, their models were revised to represent their broader understanding. In this work, Lehrer and Schauble had students working with similar prompts throughout their designed learning experience, which supported them to create progressively more sophisticated models over time.

Science Education Reform: The Next Generation Science Standards

One of the areas of emphasis in the *Framework* (National Research Council, 2012) and *Next Generation Science Standards* (*NGSS*; NGSS Lead States, 2013) is Earth's surface processes. Specifically, the *NGSS* include standards associated with the processes that drive the movement of water on, through, and above Earth's surface. For example, one of the middle school earth science standards focused on Earth's surface processes is (MS.ESS-ESP.b) "Model multiple pathways for the cycling of water through the atmosphere, geosphere, and hydrosphere as it changes phase and moves in response to energy from the sun and the force of gravity" (NGSS Lead States, 2013). This standard incorporates both the water cycle and the watershed concepts, but instead of focusing on defining the concept, it focuses on students' understanding of the processes that make up the water cycle and watersheds.

In the development of the *NGSS* standards, the authors made the standards publicly available and open for comment at several times. In the revision process, the language of individual standards was changed, along with some of the components of the standards. Table 1 shows how the language of the standard about modeling the movement of water in Earth's surface processes changed between the May 2012 version (NGSS Lead States, 2012) and the final version in April 2013 (NGSS Lead States, 2013). The similar elements are highlighted, and even some of *them* changed between the two versions. One element that changed but is not identifiable from the language of the standard is the crosscutting concept.

In the May 2012 version of the standard, the crosscutting concept related to systems. In the May 2012 version, the systems crosscutting concept was "models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems." In the context of the disciplinary core idea and science practice, it was can be interpreted that students were meant to develop models of water systems. In the final version of the standard (see Table 1), the crosscutting concept became about matter and energy.

Table 1. A Comparison of the Draft and Final Versions of a *NGSS* Performance Expectation

Version	**Performance Expectation**
May 2012	MS.ESS-ESP.b: **Model** multiple pathways for the *cycling of water through the atmosphere, geosphere, and hydrosphere* as it changes phase and moves in response to energy from the sun and the force of gravity. (CCC: <u>Systems and system models</u>)
April 2013 (Final Version)	MS-ESS2-4: Develop a **model** to describe the *cycling of water through Earth's systems* driven by <u>energy from the sun and the force of gravity</u>.

Note. The three dimensions are highlighted using bold (science practice), italics (disciplinary core idea), and underlining (crosscutting concept).

Three Dimensions of Science Education

The *NGSS* transform the science education principles outlined in the *Framework* into standards that integrate three dimensions. For each grade level and subject area, the *NGSS* pull together science practices and disciplinary core ideas, with crosscutting concepts. The page with the standards shows more-thorough descriptions of the elements being combined, the disciplinary core idea, science practice, and the crosscutting concept (Table 2). Although the descriptions provide additional detail for the standards themselves, it is likely that this connection and additional detail will be lost when the standards are translated into state standards. Although these additional explanations provide some context, the *NGSS*, like the *Framework,* lack reference to the practice of education.

Table 2. A May 2012 Draft Version of a *NGSS* Performance Expectation and the Published Supplemental Information

MS.ESS-ESP.b: Model **multiple pathways for the *cycling of water through the atmosphere, geosphere, and hydrosphere* as it changes phase and moves in response to energy from the sun and the force of gravity. (CCC: Systems and system models)**		
Science Practice **Developing and Using Models:**	**Disciplinary Core Idea** *The Role of Water in Earth's Surface Processes:*	**Crosscutting Concepts** Systems and System Models:
• Use and/or construct models to predict, explain, and/or collect data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs.	• Earth's surface processes are the result of energy flowing and matter cycling within and among the planet's surface systems. This energy is derived from electromagnetic radiation from the sun. This flow of energy and cycling of matter produce chemical and physical changes in Earth's surface materials and living organisms. • Water continually cycles among the land, ocean, and atmosphere via transpiration, evaporation, condensation, precipitation, and the downhill runoff on land. Global movements of water and changes in its chemical phase are driven by sunlight and gravity.	• Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter and information flows within systems. Models are limited: in that they only represent certain aspects of the system under study.

The disciplinary core ideas emphasized in the *Framework* (National Research Council, 2012, chapters 5-8) resemble what has been described as "big ideas," or the essential part of the scientific concept (Krajcik, McNeill, & Reiser, 2008). The rationale for focusing on core ideas comes from a variety of reports in the literature. Studies have shown that the number of standards presently included in state documents leads to the mile-wide and inch-deep coverage of science topics, especially as some states (e.g., Michigan) include mandates that all standards be included in state assessments. Through focusing on the core ideas, states can develop standards that emphasize a deep understanding of a limited number of science concepts (National Research Council 2012).

Another organizing principle of science knowledge is the themes that resonate across disciplines, which the *Framework* calls crosscutting concepts (see National Research Council, 2012, chapter 4, for a complete list). Crosscutting concepts have long been considered an important part of instruction, but one that curriculum developers have struggled to make apparent

(Krajcik et al., 2008). The intent of including crosscutting concepts in the three dimensions is for standards and instruction to be explicit about the connections across science concepts and disciplines (National Research Council, 2012).

The final of the three dimensions is science and engineering practices. This work focuses only on science practices, which are activities that are common throughout all disciplines of science, including the development of models, carrying out of investigations, and scientific explanation. This research focuses on the ways that a single science practice (scientific explanation) can be fused with disciplinary core ideas and crosscutting concepts. Scientific explanation is described as a claim about a phenomenon, supported by evidence from valid and reliable data and scientific theory, and a representation that describes and explains a process (NGSS Lead States, 2013).

Although the three dimensions are the major focus of the document, the *Framework* identifies the need for clear examples of what integration of the three dimensions looks like in curriculum and instruction. This is a clear weakness of the *Framework*. The document lacks examples of how students are expected to integrate the described knowledge. Although Chapter Nine attempts to outline how the three dimensions can be integrated, the results are not well fleshed out and do not cite any curricular examples of excellence, depending instead on the development of new curricula. Before curricula can be developed, we need a clear understanding of what the results should look like. The text in italics in both versions of the standard, "energy from the sun and the force of gravity," becomes a representation of the crosscutting concept. Although this language is also present in the disciplinary core idea, its representation of the role of energy in the movement of matter represents a theme that cuts across science. This is seen more clearly in Table 2, which takes the draft version of the standard and breaks down the disciplinary core idea, science practice, and crosscutting concept to more clearly show the role of each in this version of the standard.

Integrated Science Understandings

Although content and practices have been emphasized in various science education reform documents over the years, the *Framework* (National Research Council, 2012) continues to address the problem of disparate discussion of content and practices (and crosscutting concepts, a new theme). Like previous documents, including the *National Science Education Standards* (National Research Council, 1993), the *Framework* (National Research Council,

2012) discusses content and practices in separate sections. Although a section discusses the integration of these concepts, *how* to integrate the ideas is left unclear.

An integrated understanding of science content was described in a book on curriculum coherence (Roseman et al., 2008). The book was based on the elements of curriculum that develop students' integrated understandings using a knowledge-integration (Linn, 2006) perspective. In the chapter they contributed to the book, Roseman, Linn, and Koppal (Roseman et al., 2008) defined integrated understanding as follows:

> *Integrated understanding, the desired set of connections among scientific ideas that students need as they progress through school. Goals for integrated understanding emerge from careful analysis of science topics and content standards.* (Roseman et al., 2008, p. 13)

These authors then described a set of principles to be followed for developing curriculum that promotes students' knowledge integration and leads to integrated understandings. These principles focused on using learning goals–driven investigations to support students' development of knowledge, and using current learning technologies whenever they might enhance student learning.

Although Roseman, Linn, and Koppal's (2008) use of the term "integrated understanding" is similar to how the *NGSS* describe an integrated understanding, in that they highlight making connections across time and content areas, some important differences are worth noting. Perhaps related to the timing of the publication of the book, their definition does not include reference to the integration of science content and practices (DCIs, SPs, and CCCs) in a particular unit, or across time. They focus on the development of connections, without specificity about what types of connections might be promoted. In the *NGSS*, the focus is on students' development of deeper understandings of content, DCIs and CCCs, while also developing their use of the SPs in the context of a curricular unit. The *NGSS* also focus on the development of connections across DCIs through the use of the themes from the CCCs over time, while also developing students' use of practices to develop new knowledge of content over time.

There is not complete agreement about what should be prioritized in the development of cohesive integrative curriculum materials. In their research on the development of learning goals–driven curricular materials, featured in the same volume, Krajcik and colleagues (Krajcik et al., 2008) added the component of contextualization to their description of the important components for learning, while focusing on the sequence of the activities in the unit.

Much research has looked at how bi-dimensional integration develops in science classes (e.g., McNeill & Krajcik, 2008; Songer et al., 2009) without calling it "integration." Songer and colleagues, as well as many others, have focused their research on the overlap between disciplinary core ideas and science practices. For example, Songer and Gotwals (Songer & Gotwals, 2012) focused on elementary students' development of scientific explanations in the content area of biodiversity. They examined the scaffolds that supported students' construction of meaningful explanations. Similarly, Lehrer and Schauble (Lehrer & Schauble, 2000) examined the ways in which students revised their models of elbows as they understood more about the role of joints. These researchers focused on the students' representation of disciplinary core ideas in the context of SPs, here called one of three types of bi-dimensional integration (Figure 1). Both the *Framework* and *NGSS* specify integration as an important component of the new standards, but the integration of all three dimensions has not been studied.

Songer and Gotwals (Songer & Gotwals, 2012) took a different approach to the integration of content and practice, focusing on "fusion" within learning goals, and their alignment with assessment products. Their research group integrated science content and science practices, with both dimensions appearing in every learning goal. Songer and Gotwals argued that it is impossible to gain a deep understanding of content without coordinated learning about science practices, and vice versa. Their work took strong positive steps toward characterizing fusion in students' representations of knowledge. They addressed fusion from the perspective of assessments, and they focused exclusively on fused products of learning.

The crosscutting concepts have long had a place in science education standards and curriculum recommendations. Clear parallels exist between the *NGSS* CCCs and other broad, overarching themes that have been identified and incorporated into the *National Science Education Standards* (National Research Counctil, 1996)*, American Association for the Advancement of Science* (AAAS, 1993)*,* and the *College Board* (College Board, 2009) though never as described by the *NGSS* (Duschl 2012). The crosscutting concepts in the *NGSS* are intended to be broad themes that support students in making sense of new content (NGSS Lead States, 2013). One distinct difference between the *NGSS* and previous work is the integration not only of content and practices but also of the crosscutting concept into each individual standard, called a performance expectation in the *NGSS*. In the context of this study, a representation of a tri-dimensional integrated understanding is as follows:

- A representation of a concept (Science Practice)
- that includes the phenomenon and the mechanism driving the process (Disciplinary Core Idea)
- and shows how this phenomenon relates to other science concepts (Crosscutting Concept)

It is possible for students to have an inaccurate understanding of the concept that is expressed as an integrated understanding, if they successfully use the science practice.

Integration of the dimensions is not an indication of accuracy, but it is expected that evidence of an integrated understanding would be more likely to reveal a greater depth of understanding than a statement that attends to only one of the three dimensions. It is also assumed that the presence of information alone is not indicative of integration of ideas. Integrating knowledge requires more than presence of knowledge: It requires the information to be linked in some way to other knowledge.

In the *NGSS*, crosscutting concepts are described as an organizing principle to support students in making sense of new information. It is clearly stated that students should not be assessed on the basis of the crosscutting concepts themselves, but that knowledge of the crosscutting concept should be associated with students' understanding of the disciplinary core idea. This makes separating the crosscutting concept from the disciplinary core idea difficult. Students are expected to have knowledge of the crosscutting concept both independent of the disciplinary core idea and inseparable from the disciplinary core idea. The independence and dependence of the crosscutting concept makes designing instruction challenging, as it appears to need to be both implicit and explicit. This problem also seems to be tied to the perennial challenge of education, the problem of transfer of learning across subject areas (Bransford & Schwartz, 1999; Bransford et al., 2000).

A weakness of both documents, the *Framework* and *NGSS*, is the lack of concrete examples. The absence of description of how the standards might play out in classrooms leaves some challenges for implementation. For example, the *NGSS* require teachers to use models, without examples of which models to use, or for what purpose. Educators apply the word "modeling" to three distinctly different science practices, which can result in confusion when attempting to incorporate the practice into classrooms. Both documents do provide background that helps teachers and policy makers understand the purpose of the models used. The supporting materials are strong in their explanation of how the described elements relate to the larger goals of instruction. Although they are successful in breaking down the learning goals, little if any work has been done on what the knowledge that fuses disciplinary core ideas, science practices, and crosscutting concepts looks like, and how to get students to express fused knowledge.

Only one document has described how integrating the three dimensions described by *NGSS* might look in classrooms. Bybee (Bybee 2013) approached the integration of the three dimensions by suggesting that teachers plan to foreground and background particular dimensions at various points in the unit. Bybee provided teachers with a worksheet describing which of the dimensions might be in the foreground or background of a particular lesson in a unit. Although this concept of foregrounding and backgrounding dimensions seems to be helpful in planning a unit, it does not provide suggestions for how the dimensions might be integrated within a lesson, and it leaves open the question of whether and when the three dimensions might or should be integrated together.

The Three Dimensions of the Curricular Unit

Disciplinary Core Idea: Earth's Surface Processes

Research has shown that watershed literacy is a problem, and the problems that students need to understand have changed significantly in recent decades. Historically, the sources of environmental pollution were easily identified, and blame was easy to assign. Corporate contributions to water pollution made up the point-source pollution. In the 1970s and early 1980s, the leading cause of water pollution was industrial, but the Environmental Protection Agency's laws and the legal pursuit of environmental cleanup essentially eliminated this source through regulation of factory emissions. Presently, the leading source of water pollution is runoff and drainage linked to residential and commercial contributions more than industrial sources. Gravity and environmental surface materials of dictate where water flows, leading most water underground or into human wastewater systems.

As the pollution sources have changed, the knowledge needed by students to address water problems has also changed. To develop a water-literate citizenry that can participate in making decisions about the disposal of natural and chemical contaminants, students (and adults) should be familiar with the following watershed principles developed by Endreny (Endreny 2010), based on those developed by Shepardson and colleagues (Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2009):

> *The water cycle (precipitation, evaporation, condensation, infiltration and run-off) is responsible for the water in the watershed. A watershed is any body of water and the land that drains into that body of water. Topography defines and separates the watersheds. Smaller watersheds connect to each other forming larger more inclusive watersheds. Land use in watersheds affects water pollution. This includes run-off pollution. A watershed contains biological components that interact and influence the watershed. The watershed contains physical and biological components. A watershed is influenced by human and natural factors. (Endreny 2010)*

Because the major sources of water pollution are not localized, they are difficult to regulate. The best approach for reaching the public, and for achieving change in water quality, is through education. Although there is some disagreement about how to reach the public, the common factor that bonds all citizens is public education.

In the context of teaching about the role of water in Earth's surface processes, Endreny's (2010) definition of a watershed draws on three main components. First, students need to understand how water moves on Earth's surface and how the materials that compose the surface influence the movement of water. Second, students need to understand what topography is, and how it influences the flow of water. Third, students need to understand how humans affect what is in water through their actions on Earth's surface, and to understand the changes that we make to the surface materials. Each of these components can be represented using various types of models.

Science Practice: Explanation

Scientific Explanations

There are multiple perspectives on how to differentiate between the practices of scientific explanation and argumentation, and how to see where they overlap (Berland & McNeill, 2012; Bricker & Bell, 2008; Duschl & Osborne, 2002). One view of the relationship between the practices focuses on the form that the practice takes. For example, argumentation discourse might precede the science practice of a written explanation. In this work, scientific explanation is a written description of the students' response to the scientific question. This research focuses on scientific explanations in which students include a claim, evidence, and reasoning to support their understanding of the scientific phenomenon (e.g., McNeill, Lizotte, Krajcik, & Marx, 2006; Songer 2006). Significant research on students' development of scientific explanation in elementary and middle school has shown that young students are capable of complex thinking and reasoning (Songer et al., 2009), but that students need significant support to develop the practice of scientific explanation (Songer & Gotwals, 2012). Even in older grades, students need support from teachers and curriculum materials as they develop the practice of explanation (McNeill & Krajcik, 2008). One means of support is to provide students with written curricular scaffolds that prompt them to provide a claim, evidence, and reasoning (McNeill et al., 2006). Other research built on the written scaffolds, focusing on the ways that teachers use in-class talk, providing students with verbal scaffolds for related processes, such as selecting evidence and forming complete sentences focused on the scientific question; the written and verbal scaffolds were found to be complementary forms of support more customizable to the learners than written scaffolds alone, and, when used together, they allowed the teacher to provide students with the additional support needed to make the goal accessible (Songer, Shah, & Fick, 2013).

Conceptual Models

The *NGSS* include the science practice of conceptual modeling with “constructing explanations,” where they say, “Construct an explanation using models or representation.” For the purpose of this research, a conceptual model is used to describe the students’ drawings of their understanding of a science concept or process (Schwarz et al., 2009). According to Schwarz and colleagues (2009), advanced conceptual models should incorporate different scales into their illustration of the phenomenon, and should describe the process being explored. Advanced models explain, rather than just show, the phenomenon. A school-based example of a conceptual model would be students’ use of drawings to describe their understanding of the processes involved in water cycles. An advanced middle-school-level model might use different scales to show the landscape processes (macroscopic) and also the influence of substrate porosity (microscopic) on the movement of water. At the high school level, one might expect to see water’s polarity have an influence on water movement, as well as on the evaporation and condensation of water. Conceptual models illustrate a students’ mental model of the phenomenon of interest. Depending on how they are used, conceptual models can represent students’ current understanding of the scientific concept (Lehrer & Schauble, 2006; White & Frederiksen, 1998) and can provide students with the opportunity to develop several representations of the same science concept. Despite the word “model” in the name of this practice, the way we use the practice falls under the category of explanation rather than modeling.

Science Practice: Developing and Using Models

Modeling is considered to be an important part of science practice. Scientists use numerical, physical, and conceptual representations of interactions to model natural phenomena. These models help scientists understand the interactions that take place between elements in a system. Modeling allows scientists to make choices about which parts in the system to focus on. Similarly, when students work with models, they can select elements of the system that allow them to focus on understanding parts of a phenomenon. Students can then take these parts and fuse them into an understanding of the bigger picture. Science education describes students' interaction with each of these types of models depending on the phenomenon and educational context. In terms of students' understanding of the water cycle and watersheds, it is possible for a teacher to use each of these models to represent the phenomena.

Developing Physical Models and Investigations

Adding to the complexity, models can be used in many ways to improve understanding. The *NGSS* include a progression specifying how students might deepen their knowledge of the modeling practice across grade levels, and they include a variety of uses for models that make up the practice. At the middle school level, the NGSS specify the following uses for models:

- To evaluate limitations of a model for a proposed object or tool
- To develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed
- To use or develop a model of simple systems with uncertain and less predictable factors
- To develop or revise a model to show the relationships among variables, including those that are not observable but that predict observable phenomena
- To develop or use a model to predict or describe phenomena
- To develop a model to describe unobservable mechanisms
- To develop or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs and those at unobservable scales

The *NGSS* focus on using models for a particular purpose is not very different from the list, generated by Schwarz and colleagues (2009), of ways that models are used. These authors distilled model use into four different purposes: "*construct* models to illustrate, explain, or predict phenomena; *use* models to illustrate explain and predict phenomena; *evaluate* the ability of different models to accurately represent and account for patterns in phenomena, and to predict new phenomena; *revise* models to increase their explanatory and predictive power" (Schwarz et al, 2009, p. 635). Although the *NGSS* uses for models are more specific in terms of what should be examined, it becomes difficult to determine what was intended by the description. The openness in the Schwarz list of uses makes it possible to determine how the model is intended to be used, and to check whether that use is faithful to the intention of the practice. The full list of uses emphasizes the use of evidence in the construction and revision of the models.

Although models have long played a role in students' science learning, as demonstrations or in laboratory experiments, reform documents (National Research Council*,* 2012; NGSS Lead States, 2013) emphasize the need for meta-modeling knowledge (Schwarz & White, 2005). Meta-modeling knowledge is needed for students to have a better understanding of the model as a representation of larger phenomena. In their research on modeling, Schwarz and colleagues focused on modeling as the process of students' illustrating their understanding of a concept. As students gained a deeper understanding of the phenomena, they drew increasingly more accurate and detailed illustrations of the interactions taking place. The work of Lehrer and Schauble (2006) described model-based reasoning as a knowledge that students develop through revision of their previous work. They describe the modeling process as cycles of "develop-test-revise" (p. 383). They found that over time students change their focus from a local problem or description to a more general solution. An important difference between modeling and either demonstrations or standard school laboratory experiments is that students are aware of the limitations of the model. This awareness implies a possibility for improving the model as well as the usefulness of the model in its present form.

For the purpose of this research, a physical model is defined as a physical representation of the phenomenon that a student can use to describe the phenomenon, to explain observed changes, or to predict effects. A physical model represents some aspects of the actual phenomenon faithfully, while other aspects are less faithfully represented. Advanced physical models allow the student not only to explain a phenomenon but also to predict how changes in the system affect other aspects of the system. An example of an activity in which students develop a physical model could be the development of a miniature replica of a watershed to observe the interaction of water with various elements of the watershed, such as soil, bedrock, and rivers. Physical models allow students to observe interactions that take place in a natural system on a scale that is different from that in nature.

Analyzing and Interpreting Data From Maps (Models)

A map can also serve as a model of the landscape (National Research Council, 2007). For example, a topographic map represents elevation on a two-dimensional surface. Although the elevation information is less complete than the landscape, it provides an opportunity for determining a generalized slope of the surface at any point on the map. This process of determining high and low elevation points and determining the localized slope on a topographic map involves interpreting and analyzing the information presented on the map. Although the mathematical functions are fairly simple, the process of interpreting topographic lines can be complicated and challenging for people at any level. In addition, students often have trouble with the bird's-eye-view perspective, and with representations of large-scale space (National Research Council, 2007). In the context of the standard described in Table 1 (p. 11), using topographic maps to determine the slope of the landscape can help students make predictions about the flow of water on the landscape and the location of watershed boundaries. Knowing that water flows downhill allows students to use slope to find areas of high elevation from which the water might flow in two different directions.

Crosscutting Concept: Systems and System Models

Historically, the idea of science content as a system has been applied in a number of ways. Here, we use the crosscutting concept of systems and system models as described by the *NGSS*:

> *Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. Models are limited in that they only represent certain aspects of the system under study.* (May 2012 draft; NGSS Lead States, 2012)

From this, we can surmise that the primary components of a system include the inputs, outputs, nested systems, and processes that occur within the system. Here, the use of the crosscutting concept, systems, is conceptualized as a way to make connections between content areas, and as a frame that provides a common language for thinking about the various parts of a system. For example, if one knows very little about a particular content area but has plenty of experience with systems, he could use the frame of systems to understand which questions he might want to ask. Alternatively, if one is experienced in a content area but has little experience with systems, his knowledge of that content area could support the building of an understanding of how this context relates to other contexts.

The Development of Integrated Science Understandings

Both the *Framework* and *NGSS* specify integrated understandings as an important component of the new standards. Many studies have looked at how bi-dimensionally integrated understandings develop in science classes (e.g., Songer et al., 2009; McNeill & Krajcik, 2008) without calling them integrated. Bi-dimensional integration is conceptualized as the overlap between any two of the dimensions, disciplinary core idea, science practice, or crosscutting concept (see Figure 1 for a Venn diagram of the overlaps among dimensions). This research has focused specifically on the ways in which the crosscutting concept could be integrated with science practices and disciplinary core ideas, as those areas of overlap have not been studied to date.

To help describe the types of integration, Figure 1 was developed to provide an initial description of the types of overlap. The working definition (Figure 1) takes the three dimensions specified by the *NGSS* and describes a hypothetical relationship for how components of the standard might be integrated. It is possible that any two of the three dimensions, or potentially all three, could overlap. Elaborating on this understanding, Figure 1 is a Venn diagram of the components of the standard, with all three components overlapping in the center.

In the context of this study, a tri-dimensionally integrated understanding, the center union of the Venn diagram, is a student's representation of the role of water in Earth's surface processes (disciplinary core idea) in a model or explanation (science practice) that emphasizes the elements that make the representation a system (crosscutting concept). Bi-dimensionally integrated representations are missing one element required for a tri-dimensionally integrated understanding. For example, it might be that a student described the movement of water in a model that highlights the movement using words to label important elements without identifying the elements that make it a system. This would be an example of an overlap between the disciplinary core idea and the science practice without emphasizing the crosscutting concept, systems and system models. In Figure 1, there are multiple places where two dimensions can overlap: disciplinary core idea and science practice, disciplinary core idea and crosscutting concept, or crosscutting concept and science practice. Because the science practice is not required, it is plausible that integrated speech could be found that includes reference to both the disciplinary core idea and the crosscutting concept, or potentially language that specifically references work with a science practice.

The bi-dimensional components of Figure 1 include the overlap of the crosscutting concept (systems and system models) with the science practice (modeling and explanation) called models and explanations of systems; the overlap of the science practice (modeling and explanation) with the disciplinary core idea (the role of water in Earth's surface processes) called water models; and the overlap of the disciplinary core idea with the crosscutting concept called water systems.

This research examines students' development of integrated understandings as represented in Figure 1. It was expected that through experiences with bi-dimensionally and tri-dimensionally integrated components of the standard, students would gain a deeper understanding of the processes that drive water's interaction with Earth's surface. The curricular unit was developed to include activities focused on each of the bi-dimensional components of the model as well as the tri-dimensional understanding.

Why This Work Is Needed

Although the *NGSS* standards clearly specify the need to develop students' integrated understandings of science content, little research exists that examines how this might happen, particularly in regard to the incorporation of the crosscutting concept into instruction. The goal of this research is to describe students' opportunities to learn an integrated understanding of science content, through answering the following research questions:

- In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?
- Did students' expressions of their integrated understandings change during the course of the unit? If so, in what ways did their expressed understandings change?

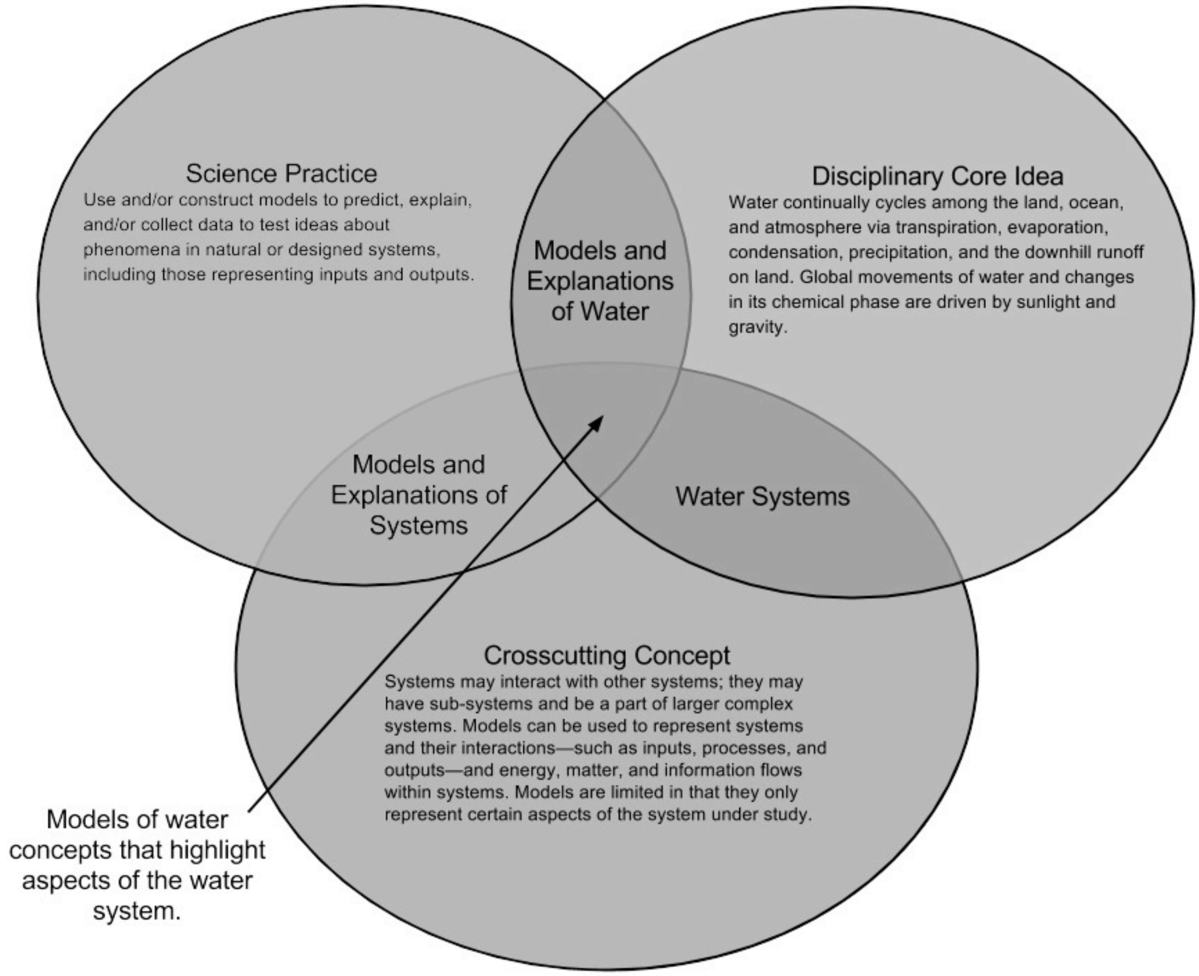


Figure 1. Diagram of the three dimensions of science education from the NGSS performance expectation of focus in the curricular unit, including potential areas for overlap. Diagram is based on the May 2012 draft version of the performance expectation (NGSS Lead States, 2012).

Chapter 3
Research Design

This study was developed to describe the opportunities to learn and the expressions of student learning associated with an integrated curricular unit. This chapter will describe the development of the curricular unit, collaboration with the teacher, and the design, data collection, data reduction, and analysis related to answering the following research questions:

- In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?
- Did students' expression of their integrated understandings change during the course of the unit? If so, in what ways did their expressed understandings change?

The Curricular Unit Development Process

The curricular unit was developed in collaboration with the middle school science teacher at a charter elementary and middle school in a mid-western university town. The science classes were composed of sixth, seventh, and eighth grade students in four class sections of mixed grade levels. Because all sixth, seventh, and eighth grade students were in the same classroom for science class, the regular curricular unit in this school is a rotating curricular unit that repeats every fourth year.

My goals for the curricular unit were to have students reach a level of understanding as described by one of the performance expectations defined in *Next Generation Science Standards* (*NGSS*) (National Research Council 2013). At the time of the development of the curricular unit, the first draft of the *NGSS* had only just been released; soon after the implementation was completed, the second draft and subsequently the third (final) draft of the standards were released. Both the *Framework* (National Research Council 2012) and the first draft of the *NGSS* helped to frame the learning goals that served as the foundation for the curricular unit.

Collaboration Between the Researcher and Teacher

Before beginning work on the present study, the teacher and I worked together on the implementation of another curricular unit with similar *NGSS*-aligned goals (Songer et al., 2012). This curricular unit included emphasis on knowledge that fused disciplinary core ideas with scientific practices, and the use of a modified learning cycle as the base of activities. For approximately 8 weeks in the spring of 2012, I was associated with the previous curricular unit as a participant observer (Patton 2002) in the teacher's science classes. This experience led to interactions between the students and me. Because many of the students were sixth and seventh graders and intended to continue at the school in the fall term of 2012, I was already familiar with approximately two thirds of the students in the science classes before the development process began for the curricular unit.

The impetus for the collaboration came from the teacher. The curricular unit was developed in collaboration with the teacher, who taught the curricular unit. Because I had previously worked with him on the implementation of another research-based curricular unit, he approached me with the desire to improve the curricular unit he would be implementing in the upcoming fall term, the theme of which was "Journeys." This year in the school's 3-year curriculum rotation typically began with an in-depth investigation of the movement of water in Earth's surface processes and moved on to an investigation of human bodies.

The teacher and I served as a development team of the curricular unit to be implemented. The teacher's goals came first in the development of activities. These priorities were based largely on the school's expectations that student learning would align with the *Michigan Grade Level Content Expectations* (*GLCE*; Michigan Department of Education, 2007). Although the *GLCE* do not incorporate the fusion of core disciplinary ideas with scientific practices, both components are in the document, in separate sections. The *GLCE* are clearly different from the *NGSS* in two areas where. First, the *GLCE* do not include crosscutting concepts. Second, the *NGSS* specify the combination of scientific content and practices that students should be prepared to see in instruction and assessments.

The topic the teacher was scheduled to teach for the unit was used as a starting point for the development of the curricular unit. The goals taken from the prior curricular unit were compared with the recently published performance expectations from the *NGSS* to identify comparable learning goals. The teacher's goals for the curricular unit focused on students' being able to answer the questions, "Why does a river flow the way it does?" and "What historically caused the river to flow that way?" The topics that the teacher traditionally included in this unit were the water cycle, watersheds, Michigan rivers, groundwater, and river health. Each of the topics, traditionally, was the focus of instruction for approximately 2 weeks, giving the unit a total of about 8 weeks of instruction. The teacher hoped that the curricular unit would connect with an annual trip the students took in September to a nearby summer camp situated in a wilderness setting. The trip served as a bonding experience for students at the beginning of the year, but the teacher also hoped to use the common experience as a foundation for understanding water systems. During the unit, the teacher hoped to continue the tradition of a field trip with a local watershed council, during which students gained experience with water quality testing. After the unit on water and water resources, the teacher moved on to a mini-unit about Hawaii.

Starting with the teacher's goals and the Michigan *GLCE* of focus, we determined a set of *NGSS* middle-school-level performance expectations aligned with those goals. From these standards, we selected two that would serve as the foundation for the unit. Using those performance expectations, Table 3 was developed, in alignment with our hypothetical learning trajectory, as the basis for the development of the curricular unit. We sketched a set of activities intended to develop students' knowledge of the disciplinary core idea (DCI), the science practice (SP), and the crosscutting concept (CCC). In this initial sketch of the curricular unit, watersheds served as frame for the curricular unit, allowing the intentional integration of the crosscutting concept throughout the unit. This frame served as a goal for the unit, for students to understand one water system and the processes that made a watershed a system. From this goal the activities for the unit were designed (Wiggins & McTighe, 2005), focusing on a variety of models that would build students' understanding of the components of the system. Using the crosscutting concept of systems as a frame was intended to ensure that integration took place throughout the curricular unit. As the curricular unit was developed, the teacher and the researcher would meet to discuss the unit plan generally, sketching ideas for specific lessons. At the end of the meeting, the teacher and the researcher would have collaboratively generated a list of activities including their goals, the guiding questions, and investigations. After the meeting, the researcher would develop a detailed activity plan, focusing on the questions that might guide a student to reach the

Table 3. Frame for the Development of the Lessons in the Curricular Unit

Lesson	*Description of Activities*	*Learning Cycle*	*Learning Goal*	*Models in the Written Curricular Activities*	*NGSS Dimensions*
	Pre-Test	Evaluate		Develop Explanations	DCI + SP
			Defining Watershed		
1	What is topography? How can we represent 3D objects in 2D? Using clay and maps to understand representations of elevation.	Engage	Analyze data to demonstrate how elevation can be shown on a 2D representation.	Use elevation data – topographic maps	DCI + SP
2	What is a watershed? Using topography to predict water flow.	Explore	Analyze data to show areas of high and low elevation.	Use elevation data – topographic maps	DCI + SP
3	How big is a watershed? Looking at maps of multiple scales to understand how big a watershed can be.	Explain	Analyze data to show areas of lower elevation where water will accumulate.	Use topographic and watershed maps	DCI + SP
			Interactions in Watersheds		
4	What besides topography influences where water will flow? Using Earth's surface materials to analyze porosity and permeability.	Engage	Analyze surface materials to show which materials are more likely to hold water and which are more likely to allow water through.	Use models of surface materials – jars of dirt, sand, and pebbles	DCI + SP
5	How are the types of materials that make up different landscapes different? Using Earth's surface materials to understand the characteristics of a landscape.	Explore	Analyze surface materials to show how various combinations of materials influence the composition of a landscape.	Use models of surface materials – layers of dirt, sand, and pebbles	DCI + SP
6	What are the important aspects of a watershed to preserve in a model? Planning a model of a particular type of landscape.	Explore	Develop a model of a landscape intended to function in a manner similar to the real thing.	Develop models of landscapes – layers of dirt, sand, and pebbles	DCI + SP
7	How does water influence the landscape? Adding water to the models developed by students to observe the movement of water.	Elaborate	Describe how water interacts with the model of a landscape.	Test models of landscapes – layers of dirt, sand, and pebbles	DCI + SP
8	How does what we add to Earth's surface affect ground and surface water?	Explain	Describe the impact of manmade surfaces and pollutants on a landscape.	Test models of landscapes – layers of dirt, sand, pebbles, and food coloring	DCI + SP
			Watersheds as Systems		
9	How do systems help us understand the natural world?	Synthesis	Describe the characteristics of a watershed that make it a system.	Develop models – draw models of watersheds as systems	DCI + SP + CCC
	Post-test	Evaluate		Develop Explanations	DCI + SP

Note. The dimensions column shows which dimensions were designed to be present in the lessons, but this does not necessarily mean these dimensions were enacted, nor that they were integrated.

goal. At the next meeting, the researcher and the teacher would meet to review the activities that were developed and begin to discuss the next lesson. Whereas both the teacher and the researcher participated in the development process, it was the researcher who wrote the activities for the curricular unit, after significant discussion with the teacher. It was the teacher who crafted the in-class discussions, based in part on conversations during interviews with the researcher about difficulties students were having.

Principles Used in the Development of the Unit

Learning-Goal-Driven Activities Aligned to Standards

The development of the activities started with the Michigan *GLCE*, on which the teacher's curricular unit and sequence of topics were based. From there, we identified *NGSS* standards that aligned with the *GLCE* content.

> *Model multiple pathways for the cycling of water through the atmosphere, geosphere, and hydrosphere as it changes phase and moves in response to energy from the sun and force of gravity*. (May 2012 draft; NGSS Lead States, 2012)

Because the *GLCE* discuss content and practices separately, the focus was on alignment with science content. Once the content standards were identified, a learning goal and its related driving question were determined for each lesson. It was initially believed that each lesson would address the crosscutting concept by discussing the focal system—that is, watersheds. During analysis, however, the researcher's understanding of how systems might be included was revised, and a more strict definition was adopted in which the components of a system had to be included for systems to be discussed. 3 shows the learning goals for each lesson along with the dimensions of science education that serve as the focus for that lesson.

Modified Learning Cycle of Knowledge Development

The unit was developed to unfold through a modified learning cycle (Songer, 2006), as described in the literature review (p. 8). Both the unit and the individual lessons were developed in alignment with the modified learning cycle. Each lesson served the role of one component of the learning cycle, and each part of an individual lesson also had a learning cycle component. In each lesson, which often unfolded over a number of class periods, there were elements of the Songer learning cycle. Each lesson started with a contextualizing component in which the material from the day before was reviewed more concretely (Engage), followed by students working with various models and data for analysis (Explore), which they answered questions about (Explain), and finally the lesson concluded with the students synthesizing their knowledge through the development of conceptual models and scientific explanations (Synthesis). The learning cycle was also employed over the unit as a whole, as shown in Table 3 (p.29), and each lesson had a role in building students' knowledge of the broader systems and concepts. The decision to use the learning cycle on two different scales was based on the two different scales of knowledge being developed. In the individual lessons, students built on their prior knowledge and developed new understandings through experience with the phenomena. On the scale of the unit, students built knowledge and experience with the broad themes of science; the details are less important on this scale, but the knowledge built in each lesson contributes to the students' understanding of the themes of science. For example, it was intended that students would use their knowledge of elevation, from lesson 1, and the flow of water on the surface, from lesson 2, to build their knowledge of what determines where a watershed boundary is located (a component of the crosscutting concept systems), in lesson 3. Although evaluation is not a component of the Songer learning cycle, the research-based goals for the curricular unit dictated having an evaluation at the beginning and end.

Supporting the Development of Science Knowledge Through Science Practices

As described in Chapter 2, integration of science content and practices has long been thought to be a way to better prepare students for understanding science and becoming scientists (National Research Council, 2007). In each lesson, students learned about a component of the disciplinary core idea in the context of a science practice. In each lesson, either the depth of their understanding was intended to change through a closer examination of one aspect of the DCI, or the students used a new science practice with which to explore the DCI. Relating one practice to another, as was done in lesson 1 (see Table 3, p. 29), gave students the opportunity to understand how representations of data related to reality. At the conclusion of each lesson, students synthesized their understanding of the disciplinary core idea through engagement with two other science practices, conceptual modeling and scientific explanation.

Models as Tools for Developing Understanding of Systems and Phenomena

The standard on which this unit was based specified that students should be using the scientific practice of modeling to better understand the movement of water on, above, and through the surface of Earth. As described by Harrison and Treagust (2000), a wide variety of practices fall under the heading of modeling. In this research, three types of models were used. Early in the unit, students developed a scale representation of an aspect of the phenomenon, a physical model. In lesson 1, the students created clay models of mountains, which were sliced to show how topographic lines relate to the physical landscape. Using their knowledge of topographic lines, students then related the topographic map models of the landscape to the physical landscape in order to make predictions about how water might move on the surface of Earth. Finally, students created conceptual models that showed their understanding of how the process worked.

In early lessons, the physical models allowed students to create representations of the actual phenomena that were consistent with reality in some aspects but divergent in others. These representations allowed students to make predictions and collect data about how water interacts with the layers of the landscape. Topographic maps were used as large data sets for analysis. The graphical representations of data provided information about the elevation of various points, allowing students to analyze changes in elevation, informing their predictions of the movement of water. Through analysis activities, students were able to identify high points in the landscape that act as dividing lines between watersheds. The conceptual models were used as a tool for elaborating and explaining students' understanding of the phenomenon (discussed further below).

Conceptual Models and Explanations as Representations of Students' Understanding

At the conclusion of each lesson, students completed both an explanation and a conceptual model. The conceptual models were assignments in which the students received a brief prompt and were asked to create a drawing of how the student understood the system or process to work. Students' models were used in collaboration with the written scientific explanations that the students also created about similar content. Example prompts for the models and explanations are included in Table 4, including the dimensions integrated in the prompt. The last two columns of Table 4 are examples of the post-enactment analysis of the dimensions included in the prompts, explained in the "Homework – Conceptual models and scientific explanations" section of this chapter (p. 42).

Table 4. Example Written Curricular Prompts

Lesson	Science Practice	Prompt	Dimensions	Integration
3	Explanation	Write a scientific explanation that answers the scientific question, How big can a watershed be?	DCI + SP	2 Dimensions
3	Model	Draw a model of a watershed. Make sure to include what influences how big the watershed is and what influences where the water goes.	DCI + SP	2 Dimensions

These assignments were intended to be used as formative assessments to guide the teacher's plan for conversation and activities in the subsequent lesson. These assignments could also serve as an opportunity for the teacher to provide individualized feedback to the students about their science practices during the unit. Ideally, the models and explanations would be completed in class, with an opportunity for students to discuss their understandings as they developed their models. In the implementation of the unit, the models and explanations were done as homework. However, because they were completed at home, they were at times influenced by external contributors such as the internet or parents. One student confessed during an interview that her father had helped her complete her homework assignment (the conceptual model).

Students did not receive feedback on their models but were given oral instructions during class about what elements should be included in their models. The prompts for the models and explanations varied only slightly over the course of the unit, providing students with opportunities to create new representations of their understanding.

Revision of Students' Understandings

The prompts for each of the conceptual models and scientific explanations were intentionally similar to provide students with the opportunity to start afresh. As students learned a conceptually more complex understanding of what a watershed is, they were given the opportunity to revise their thinking as represented in their conceptual models (White & Frederiksen, 1998). Rather than giving students back their old conceptual models, each student was provided with a fresh sheet of paper with a similar prompt for each model. Because students were not directly using their previous version, they were required to represent their understanding at that moment, making it a little harder to depend on their previous understanding.

These separate models provided a valuable learning opportunity when students were asked how the models were similar to or different from one another in an interview.

Integration of the Three Dimensions

The *NGSS* performance expectation for this unit emphasizes the mechanisms for the movement of water through Earth's systems:

> *Model multiple pathways for the cycling of water through the atmosphere, geosphere, and hydrosphere as it changes phase and moves in response to energy from the sun and force of gravity.* (May 2012 draft; Achieve, Inc., 2012)

This original version (May 2012) of the standard emphasized the movement of water through each of Earth's systems and incorporated the crosscutting concept, systems, and system models. Later versions (MS-ESS2-b, January 2013; MS-ESS2-4, April 2013) focused on "the cycling of water through Earth's systems," which turned the focus away from the interactions in those systems, and changed the crosscutting concept to energy and matter (MS-ESS2-4, April 2013).

CCC + DCI: Water systems

When we focus on the crosscutting concept in the original standard, systems, and system models, we see two ways in which this CCC was intentionally integrated with the disciplinary core idea—water in Earth's surface processes—in the curricular unit. Because the standard emphasized both the water cycle (a water system) and the interactions with Earth's spheres (geosphere, hydrosphere, atmosphere) in the original standard, a second system was chosen as a frame for the curricular unit.

Because of our focus on how water moves through the spheres, the water systems concept of a watershed served as a frame for this entire unit. Watersheds illustrate the influence of elevation on the possible path of the water, and they can be defined using the *NGSS* description of systems. This focus on the water system of watersheds implicitly integrated the CCC throughout the curricular unit. In the unit, students experienced aspects of the water system as they focused at various times throughout the unit on different aspects of the CCC, systems.

Using the *NGSS* description of systems, the concepts of inputs, outputs, processes, boundaries, and nested systems were identified as key components of the definition. The following system components are explained using the corresponding component of a watershed, highlighting the integration of the DCI and CCC inherent in the concept of watersheds.

1. Inputs: Water in a watershed comes both from the atmosphere and from smaller systems that make up any larger system. Water can also be contributed to an area through the movement of water by living things—plants and animals, including humans.
2. Outputs: Water in a watershed can leave the watershed for the atmosphere or a larger watershed. A large portion of Earth's fresh water resides underground as groundwater, and water maintains a longer residence if it reaches this pool.
3. Processes: In a watershed, water interacts with organisms (plants and animals) as well as with the geosphere and hydrosphere. Water is a part of many surficial processes.
4. Boundary: The boundary of a watershed relates to the location of higher elevation. Elevation determines the destination of water. The slope of the surface sends water that does not infiltrate the surface along the surface to a body of water at a lower elevation.
5. Nested systems: Each watershed is part of a larger system of watersheds, all of the water from which (if it is not headed into groundwater or the atmosphere) is destined for a larger body of water. An example from my hometown is the Delaware River, which is composed of many different rivers that join together, including the Schuylkill River and the Brandywine River. Ultimately, the Delaware River becomes part of the Delaware Bay and then the Atlantic Ocean. Each of these bodies of water has its own watershed, which in turn is part of a larger watershed.

During the class, each of these concepts is discussed in terms of what makes an area a part of a watershed. The concepts are not always explicitly described as being related to what makes a watershed a system, but they are an integral part of defining the system as students develop their definitions.

Throughout the curricular unit, the focus was implicitly on the CCC of systems, but in one lesson there was an explicit focus on integrating what students had learned with the CCC. Although the standards focus on using the CCC to frame students' learning of new content, that approach assumes that students are already familiar with the CCC and can apply it to new information. Here, the students were not already familiar with the CCC. As a result, the unit focused on using the CCC as a synthesis through which students could make sense of what they learned. Lesson 9 focused on teaching students about the CCC in the context of other content, and then it applied the principles of the CCC to the content they had just learned (Table 3, p. 29).

Clarifying the DCI: The mechanism for the movement of water

In the curricular unit, the mechanism for the movement of water was discussed in terms of elevation and the slope of the landscape. Although some students spontaneously mentioned the force of gravity, most students used terms such as "down," "elevation," and "downhill" to describe the mechanisms driving the movement of water. Because the performance expectation focuses on the force of gravity and on energy from the sun as the causes of the movement of water (also the focus of the revised crosscutting concept), future iterations of the curricular unit should focus on the influence of energy on the system. During the course of instruction, watersheds were defined in the following ways:

1. The land that drains to a particular body of water
2. Where water moves to progressively larger bodies of water
3. They can be nested within one another
4. They include the water below the surface of Earth

Throughout the unit, students were asked to draw models in response to similar prompts. It was expected that as students learned more about watersheds, they would emphasize and add different components to their models, incorporating new ideas into their prior understanding.

DCI + SP: Analyzing elevation data to predict the movement of water

An intentional design of the curricular unit was to incorporate representations of elevation into the curricular unit to help students build an understanding of watersheds. It was decided that topographic maps provide an excellent data set of elevations for students to analyze, and that students may not have had significant prior experience with topographic maps. Through the analysis of the elevation data presented on topographic maps, students were able to identify areas of high and low elevation values and to make predictions about the direction of water flow. To give students experience with interpreting and analyzing topographic maps, we wanted to give student an opportunity to develop a topographic map and to gain experience with translating elevation to a two-dimensional surface. These experiences with developing topographic representations were intended to support students' subsequent analysis of similar representations.

DCI + SP + CCC: Locating the boundary for a water system, watershed

After working to develop their understanding of the flow of water on Earth's surface, students analyzed the elevation data on the topographic maps to locate watershed boundaries by finding areas of high elevation from which water flowed to two different bodies of water. The activities were developed so that students would move from predicting the direction of water flow (DCI) to finding areas where water flowed to different bodies of water (DCI + CCC), all through the analysis of elevation data (SP) presented on topographic maps. Students used topographic maps to locate the lines along which water flowed to different bodies of water. Through this analysis, students determined the location of watershed boundaries, an integration of the crosscutting concept (systems and system models) with the disciplinary core idea (water in

Earth's surface processes) as determined through a science practice (analyzing data). This example serves as one illustration of a tri-dimensionally integrated activity.

Formative and Summative Assessments

Throughout the unit, students were asked to draw models and write scientific explanations in response to similar prompts. (See Table 3, on p. 29, for the timing of these formative and summative assessments.) It was expected that as students learned more about the topic, they would emphasize and add different components to their models, incorporating new ideas into their prior understanding. The models and explanations were intended to be used formatively and as in-class assignments. It was intended that the teacher would provide students with feedback about how to improve their models or explanations, focusing on their use of the science practice, not the content. The goal of the formative assessments was to capture students' understanding of the content at the time, so students' present understanding would not be "wrong," or "right" but could be represented in the practice more or less clearly and thoroughly. Ultimately, however, the models and explanations were not used formatively, which meant that there was little feedback to help students develop their science practices. The models and explanations became homework assignments, giving students an opportunity to use outside resources rather than merely their own understandings, and thus the teacher provided feedback only when the students completed the assignments. As a result, there was little opportunity for students to understand their progress during the unit.

Context

The School

The study took place at an urban charter K-8 school in a mid-western university town. The school had approximately 20 students per grade level at the middle school level. There was only one science teacher for middle school students. Students who were in the eighth grade had probably already had the teacher for 2 years. Similarly, seventh grade students were familiar with the teacher, having had 1 year with him. Each student was also assigned a homeroom, which met daily in the morning. Approximately 20 students had the science teacher as their homeroom adviser in addition to being in his science class. The middle school was on a block schedule for their classes. Students in the middle school switched rooms for their classes. Each class lasted 90 minutes twice a week, either Monday and Wednesday, or Tuesday and Thursday. Every section also met on Friday for 45 minutes.

The school was highly technological. Teachers had access to a computer lab, three desktop computers were available for use by students in the classroom, and the school had a class set of computers and iPads, which the science teacher regularly used. The school used the Google platform of apps for its mail and collaboration. In the middle school, students regularly submitted assignments for several of their classes using a collaboration platform called Moodle. Students were also regularly asked to submit homework assignments through Google documents. It was assumed by teachers that students had the ability to access computers and the internet outside of school, whether at home or through a public access venue such as a library.

The Students

In the four sections of science classes, there were 72 students in total, with an average of 18 students per section. The sections varied in the composition of student abilities because of scheduling conflicts (e.g., the availability of advanced math classes). Students came from a largely middle to upper class population, with less than 10% of students categorized (for testing purposes) as economically disadvantaged. The school as a whole was 72% white, 20% multi-ethnic, 4% Asian, 3% African-American, and 1% Latino students. Because all sixth, seventh, and eighth grade students participated in the described science class, the students in this study reflect the composition of the middle school as a whole. All students' parents gave permission for their children to participate in the study. Although one student's parents did not give permission for the students' data to be used in analysis, all other students were given full permission for participation.

The third class section was selected to be the primary focus of the study because it fell on the second day of instruction. The school used a block schedule—two of the sections occurred on the first day, and two sections occurred on a second day of instruction. The section of focus was the first class on the second day. In that class of 17 students, five students did not consent to participate in interviews. Of the 12 students who did consent, the 10 who were selected represented a range of achievement abilities in science and a variety of the three grade levels that made up the class (at least two from each grade level). Because students who were more likely to be talkative in an interview were selected, those with learning difficulties were less likely to be selected. Of the 10 students who were selected to participate in interviews, six regularly completed their homework assignments. The interviewers asked students to describe their homework models and explanations, so the second and third interviews included only the six students who completed their homework. Hereafter, these six students were the focal interview students. The final interview, which focused on the post-test (completed by all students), included all 10 students.

Role of Researcher and Teacher in the Study

The class was taught by a teacher with 5 years of teaching experience, all in this school with the described class structure. He came to teaching as a second career. After several successful years in consulting, he graduated from the elementary education masters-with-certification program at a local large research university. This was the second time that he had taught water concepts as part of the "Journeys"-themed curricular unit.

From the very beginning of the curricular unit development process, the teacher was made aware of the research questions, data to be collected, and the goals of the research, and he was informed of any revisions to these components of the research design. This was important because the goal was to describe students' integrated understandings about disciplinary core idea, scientific practice, and crosscutting concept. To develop a classroom environment conducive to integrated learning, the teacher also needed to hold integrated understandings as a goal of the curricular unit. This was difficult because integrated understanding as a concept had not yet been defined. We had a working definition for the implementation, but the activities and student work solidified the definition.

During implementation of the activities, I was a participant observer (Patton, 2002) in the classroom. This role was consistent with my previous experience in this classroom. During a class period, students generally did not assume that I would be available to answer questions, although there were occasions when I was a more active participant, asking and answering students' questions. During classroom discussion, I observed from the back of the classroom, but during group work and individual student work, I made myself available to answer questions and to probe students for their understanding of the activities.

Study Design

This study focuses on the case (Yin, 2014) of a single science classroom, unique because of its implementation of the curricular unit intended to integrate students' understandings. In this classroom, six students serve as focal students for a more detailed analysis of the students' understandings. During the course of the study, the curricular unit was revised to account for observations made during the implementation. These revisions consisted of the addition and removal of lessons and activities initially planned for the curricular unit. During the implementation, data were collected in the form of field notes, full-class video, small-group video, student work, interviews, and a pre/post test. The alignment between the research questions, data analyzed, and the purpose of the analysis is shown in Table 4. The data collection and analysis proceeded in the manner described below.

The curricular unit was analyzed by considering multiple embedded units of analysis (Yin, 2014). Each lesson served as an analysis unit within the curricular unit. In several lessons, the six focal students' understandings were analyzed through the use of periodic formative and summative assessments incorporated into the lessons, and they were followed up with individual student interviews about the assessments. For each lesson, the full group conversation was analyzed line by line. By examining the lessons, we can observe what the students had the opportunity to learn.

Another unit of analysis is the student, and each student's set of responses is analyzed and each represents a subset of the ways in which students absorbed the lesson. Each student who attended the lesson took the opportunity to learn in a different way. Thus, the model, explanation, and interview of each student provide information about the ways in which the students did and did not take the opportunities to learn.

Table 5. Alignment Between the Research Questions and the Analysis Process

Research Question	Data Analyzed	Purpose of Analysis
1) In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?	Video recording of full class activities Field notes Written curricular unit	To describe patterns in the ways that the three dimensions were integrated through the talk and activities of the lessons.
2) Did students' expressions of their integrated understandings change during the course of the unit? If so, in what ways did their expressed understandings change?	Scanned copies of student models Student scientific explanations Audio recording of student interviews	To describe patterns in the ways that students represented their understanding of the concept of watersheds throughout the curricular unit.

Research Instruments and Data Collection

Data were collected from all four class sections, although the analysis focused only on the work from section 3. Figure 2 compares the data collected with the data analyzed. Only those data sources that fall within the dashed or dotted outlines were analyzed to answer the two research questions. The data sources within the dotted lines were used to answer research question 1, which examined students' opportunities to learn. The data sources within the dashed lines were used to answer research question 2, which examined changes in students' understandings as represented using SPs and as described in interviews. These instruments are described later.

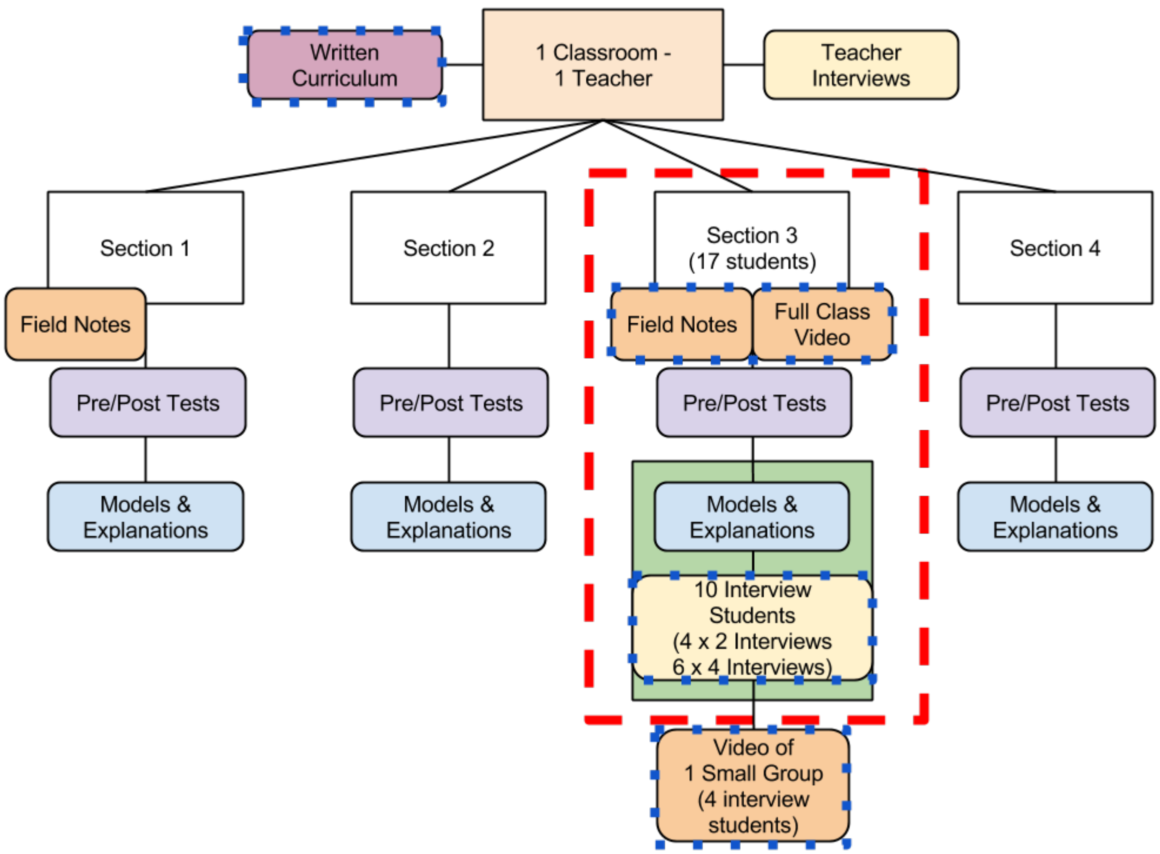


Figure 2. Data collected during the enactment of the curricular unit. Data sources outlined with a dotted line were analyzed to answer research question 1, and data outlined with a dashed line were analyzed to answer research question 2.

Student Work

Homework – Conceptual models and scientific explanations

For the conceptual models and scientific explanations, after the first lesson, students submitted a paper copy of their diagram and written work on a single, double-sided sheet of paper, which was scanned and returned to the teacher within a day. The scientific explanations from lesson 1 were submitted through Moodle, which required the procedure of matching responses (as described for the in-class work) to be completed for those explanations. All conceptual models and scientific explanations were completed as homework. Homework assignments that were completed and submitted were digitally scanned and the originals were returned to the students. The models and explanations for lesson 9 were not collected for section 3, the focal section, so this assignment was not analyzed. The analysis of the models and explanations is described in the student work section below.

Pre/post test

All students were given the same test at the beginning and at the end of the unit (full test included in Appendix B). The pre/post test consisted of nine questions. The questions included three conceptual models, two scientific explanations, and four questions that were more factually based. One of the three factual questions was multiple-choice, and the others were short answer or free response. Students were provided with at least half a page of paper for each model or explanation response. Example questions for the conceptual model and scientific explanation questions are included in

Table 6. Each question is represented along with the dimensions included in the test question.

Table 6. Examples of Integrated Questions From the Pre/Post Test

Question	**Dimensions**
Draw a conceptual model showing how water interacts with a watershed. Make sure to include how big the watershed is and what influences where the water goes. Label all parts.	DCI – Movement of water on Earth's surface DCI – Interaction between water and layers of Earth SP – Models as explanation
Write a scientific explanation to answer the question, Does the Mediterranean Sea have a watershed?	DCI – Movement of water on Earth's surface SP – Scientific explanation

Note. For each question, the right column identifies the dimensions the prompt addresses. The complete test is included in Appendix B.

In-class work – Responses to short-answer prompts

All written responses were collected from students while they participated in the activities. Most student assignments were submitted through Moodle, which allows the bulk download of all student work without names associated with the responses. After downloading the responses, student numbers were associated with the responses by going through each response individually and matching the response with the student's name. Students' responses to these assignments were not used in the analysis. The curricular unit prompts themselves were analyzed as described in the curricular unit codes section below (examples shown in Table 7). The coding system used for the curricular unit prompts was the same as that used for the classroom dialogue transcripts. The full curricular unit is included in Appendix A (p. 166), and it is analyzed in Chapter 4 (p. 63).

Table 7. Examples of the Dimension and Integration Codes Applied to Lesson 3 Curriculum Prompts

Curriculum Prompt	Dimensions	Integration
How many watersheds are associated with the Huron River?	DCI – Water flow CCC – Nested systems	2 Dimensions
What do you imagine is the largest watershed you can find?	DCI – Water flow	1 Dimension
What do you imagine is the smallest watershed?	DCI – Water flow	1 Dimension
Draw a model of a watershed. Make sure to include what influences how big the watershed is and what influences where the water goes.	DCI – Water flow SP – Conceptual modeling	2 Dimensions
Write a scientific explanation that answers the scientific question, How big can a watershed be?	DCI – Water flow SP – Explanation	2 Dimensions

Note. The first three questions were completed in class, and the final two questions were completed as homework.

Student Background Surveys

At the beginning of the unit, students were given a background survey (included with the Pre/Post Test in Appendix B). The purpose of the survey was to obtain a better understanding of the types of in- and out-of-school experiences the students had previously had with maps and models. The questions in the background survey were developed to provide an opportunity for student self-assessment of their knowledge and experience with some of the different science practices in the curricular unit. The background survey was not included in the analysis, as it was found to be peripheral to the final research questions.

Classroom Observation

Video Recording

For each class period in which the curricular unit was taught, 15 class periods in total, the same section of students was video-recorded. The times and dates for each lesson are included in The small group video was excluded from the conversation analysis, which focused on full class discussion, and it represented one small group discussion that occurred during the lesson 3 enactment to provide a contrasting case to the small group discussion that was captured on the full class video. The student interviews are described later.

Field Notes

I attended at least two class sessions of each lesson. The third class period was selected for video recording and field notes because it fell on the second day of instruction, allowing the teacher to reflect and revise. I also attended the first class period to observe the initial instruction. During that period, I took field notes of the type sometimes described as jottings (Emerson, Fretz, & Shaw, 1995). For each lesson that I attended, I maintained notes of how the class proceeded, with particular attention paid to (a) moves that the teacher made to draw together information from different parts of the lesson, and (b) comments and actions that students made that might indicate engagement or lack of engagement with the lesson. The notes were used to inform discussion in the teacher interviews, and also as support for any suggestions for instructional development.

Table 8. In the class section of focus, the full classroom discussion was recorded using a single stationary camera with an external microphone aimed at the white-board where whole group instruction occurred. Additionally, a single camera and a tabletop microphone were aimed at a small group of four students assigned to sit at that table. The small group was composed of students who had provided consent to be video-recorded and interviewed. All of the students in the small group were focal students and participated in varying numbers of the student interviews. The small group video was excluded from the conversation analysis, which focused on full class discussion, and it represented one small group discussion that occurred during the lesson 3 enactment to provide a contrasting case to the small group discussion that was captured on the full class video. The student interviews are described later.

Field Notes

I attended at least two class sessions of each lesson. The third class period was selected for video recording and field notes because it fell on the second day of instruction, allowing the teacher to reflect and revise. I also attended the first class period to observe the initial instruction. During that period, I took field notes of the type sometimes described as jottings (Emerson, Fretz, & Shaw, 1995). For each lesson that I attended, I maintained notes of how the class proceeded, with particular attention paid to (a) moves that the teacher made to draw together information from different parts of the lesson, and (b) comments and actions that students made that might indicate engagement or lack of engagement with the lesson. The notes were used to inform discussion in the teacher interviews, and also as support for any suggestions for instructional development.

Table 8. Summary of Lesson and Class Session Information

Lesson Number	*Observation Date, Minutes of Video*	*Description*	*Evidence of Students' Ideas* [a]
Pre-Test	60 minutes	Pre-Test	3 models 2 explanations
Lesson 1	10/04/12 - 100 mins 10/05/12 - 45 mins	What is topography? How can we represent 3D objects in 2D? Using clay and maps to understand representations of elevation.	1 model 1 explanation 1 interview (10 students)
Lesson 2	10/12/12 - 100 mins	What is a watershed? Using topography to predict waterflow.	1 model 1 explanation 1 interview (6 students)
Lesson 3	10/18/12 - 100 mins 10/19/12 - 45 mins	How big is a watershed? Looking at maps of multiple scales to understand how big a watershed can be.	1 model 1 explanation 1 interview (6 students)
Lesson 4	10/23/12 - 100 mins; 10/24/12 - 45 mins;	What besides topography influences where water will flow? Using Earth's surface materials to analyze porosity and permeability.	
Field Trip	10/25/12 - All day (not video recorded)	Field trip to local watershed – water quality testing on a local river	
Lesson 4 (cont'd)	10/26/12 - 45 mins 11/01/12 - 100 mins 11/02/12 - 45 mins		2 models 1 explanation
Lesson 5	11/08/12 - 100 mins	How are the types of materials that make up different landscapes different? Using Earth's surface materials to understand the characteristics of a landscape.	1 model 1 interview (6 students)
Lesson 6	11/08/12 - 100 mins (same as lesson 5) 11/13/12 - 100 mins (same as lesson 7)	What are the important aspects of a watershed to preserve in a model? Planning a model of a particular type of landscape.	1 model
Lesson 7	11/13/12 - 100 mins	How does water influence the landscape? Adding water to the models students developed to observe the movement of water.	1 model 1 explanation
Lesson 8	11/15/12 - 100 mins	How does what we add to Earth's surface affect ground and surface water?	1 model 1 explanation
Lesson 9	11/16/12 - 40 mins 11/20/12 - 30 mins	How do systems help us understand the natural world?	1 model 1 explanation
Post-Test	11/20/12 - 60 mins	Post-test	3 models 2 explanations 1 interview (10 students)

[a] Evidence of students' ideas include work assigned as homework following the lesson, and interviews about the content of those assignments.

Interviews

Student interviews

Interviews with students were focused on developing a deeper understanding of the students' in-class work and homework. The goal of the interviews was for students to describe their models and explanations using language that was different from the language they used in the representation itself. The intention was for the interview to provide additional detail about what the student intentionally included in their models and explanations, thereby providing additional information about how the students' understanding was similar to or different from their earlier understanding.

The interview used a standardized, open-ended interview approach (Patton, 2002), asking students to explain the conceptual models and scientific explanations that they had most recently developed. The full set of interview protocols is included in Appendix C. Much of the discussion focused on describing the students' work and clarifying what the elements of the models represented. Each interview also gave the student the opportunity to talk about additional elements they considered including, and why they did or did not ultimately include them in their model. Each interview consisted of questions that prompted students to verbally describe their conceptual models and scientific explanations. Students' verbal descriptions of their conceptual models provided another source of data for confirming the researcher's interpretations of the models. The researcher could also, as needed, further probe the students for additional information about the representation. In some cases, students were asked how different versions of their models were different, and why they were different. This process highlighted the changes in students' understanding, for both the student and the researcher. A second set of questions, included in

Table 9, prompted the students to describe their scientific explanations. Interviews were audio-recorded to maintain a record of the full conversation. When an obvious gesture was made by the student, the researcher asked what it meant so as to include it in the record. Interview audio recordings were transcribed focusing on a word-level transcription.

Table 9. Interview Guide for Student Interviews About the Content of Models and Explanations

Interview Question	**Emphasis**
1. Tell me about the conceptual model that you drew. *a.* What does your model illustrate? *b.* Did you consider drawing it any other way as you were creating it?	- Science Practice – Models as Explanations - Reflection on Modeling Practice
2. [2nd, 3rd, and Final Interviews] How is this model different from earlier models that you drew? *a.* Why is this one different?	- Reflection on Science Learning
3. Tell me about your explanation. *a.* What led you to write this explanation in this way? *b.* Did you consider any other responses for any of the sections?	- Science Practice – Scientific Explanation - Reflection on Science Learning
4. [Final Interview] Can you explain to me, using experiences you had in class, what happens to water after it falls to Earth as rain or snow?	- Disciplinary Core Idea – Water in Earth's Surface Processes

Teacher Interviews

The teacher was interviewed after each lesson at the end of the school day, nine interviews in total, lasting from 15 to 45 minutes. They took the form of an interview guide approach (Patton, 2002), in which the topics and issues were pre-specified but the exact questions were flexible. The starting questions were specified (Appendix D), but the follow-up questions were left open. The interview focused on a general discussion of students' understandings and student work. For any identified problems, the teacher was prompted to suggest specific instructional strategies that he might use to address the difficulties. Additionally, each interview included a discussion of the upcoming lessons and strategies based on the context of the observations from that day. The future lessons were considered to determine whether they should be revised on the basis of students' current understandings. The goal of these interviews was to assess the teacher's knowledge about effectively working with these students to teach them water cycle concepts. Each conversation was audio recorded to maintain a record of the full conversation. The interviews were not found to be central to the research question and were therefore excluded from analysis.

Data Analysis

Selection of Focal Data Sources

The data were first selected to focus on the learning and opportunities to learn of section 3. The intention was to focus on the students for whom the greatest alignment of data existed. Section 3 was the only class section that was videotaped, recording the class discussions, student contributions, and some small group discussions. Also, it was students from section 3 who were selected to participate in individual student interviews, allowing the students' homework responses to be triangulated with their interview descriptions of their work. All of the students in this section consented to participate in the data analysis.

Video Data

The video data analysis consisted of seven steps: (1) selection of data to focus only on the data sources aligned with the research questions, (2) transcription of the video, (3) the development and application of a start list of descriptive codes to all video transcripts, (4) the development of conjectures about integration of the dimensions, and the testing of those conjectures against the corpus of data, (5) the development and application of pattern-based codes representing the integration of the DCI, SP, and CCC throughout the lessons, (6) themes developed on the basis of the conjectures across data types, and (7) themes revised and clarified with input from other researchers.

Data Selection

The research questions focused on students' opportunities to gain an integrated understanding of the concept, and the ways that students' expressions of their integrated understanding changed during the curricular unit. Although all of the data contributed to our understanding of these concepts on the whole, only some of the data sources contributed to answering the research questions (see Table 5, p. 40, and Figure 2, p.41).

As the first step to analysis, the entire corpus of collected data was selected to focus only those data that directly answered the research questions. The first research question, "In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?" was found to be best answered through the full-class video, which was transcribed and analyzed and then supported by video images, the written curricular unit, and field notes.

In the pre- and post-test, the questions that focused on the micro-level scale, as was emphasized in the second half of the curricular unit, were found to be less specific and less effective than other questions on the test. Specifically, these questions did not elicit information related to concepts that the students had discussed in class. The micro-scale portion of the unit also included model and explanation prompts that varied from one another, and from the prompts used continuously in the first part of the unit. As a result, the first part of the unit, which focused on the macro-scale of the phenomena, provided a more coherent set of information and became the focus for the analysis. Specifically, the last lesson in this section, lesson 3, was found to include the greatest amount of class synthesis, including defining the phenomena and making connections to the CCC. Therefore, many of the references throughout the analysis focused on students' class experiences and learning during lesson 3.

Transcription

Each full class video was converted to an audio file, with transcription focused on the dialogue that occurred in the classroom. The transcripts focus on the full classroom conversation. Small group discussions were excluded from the transcript. Filler words were not included in the transcription, nor were false starts. Sentence fragments were left as fragments.

Unit of Analysis

Each sentence was coded as a separate unit. A sentence was defined as a statement, so sentence fragments that were never completed, as well as yes or no responses, were coded as sentences. To preserve the integrity of a complete thought composed of multiple sentences spoken by the same person about the same topic, consecutive lines were marked as belonging to a set of the same conversation using the code [SET]. A sample transcript is included (Appendix D). Although the [SET] notation was intended to help capture integration in turns of talk, this system proved difficult to analyze. Breaking the turns of talk into sentences did not ultimately appear to be a fruitful approach. Reflections on this decision and suggestions for future research are included in the discussion section.

Rounds of Codes

The first round of coding began with a start list of codes that classified the data according to its alignment with the research questions. The first round of codes classified the segments according to whether they were focused on administrative tasks, science content related to the DCI, science content not related to the DCI, unrelated to science class, a yes-or-no response, a clarification statement, or an interjection.

A second list of codes was developed using the *NGSS* appendices to classify those statements that fell into the initial category of “Science Content Related to the DCI.” The appendix sections focused on the DCIs, SPs, and CCCs were used to develop sub-codes for the dimension codes. The bullet points elaborating the middle school standard level of knowledge for each practice, from the *NGSS* appendices, were used to develop a system for coding the practices according to what students were doing. All of the science practices were reviewed, and those found in the lessons were also included using the bullet points for those practices to describe dimensions of the practice to serve as sub-dimension codes. The sub-dimensions that were not included focused on those not emphasized in the curricular unit or teaching practice, such as engineering design solutions, communicating information, and students engaging in argumentation not mediated by the teacher in conversation. The sub-dimension codes for each science practice were combined to develop a broader practice code. The description of the practice code was developed to encompass each of the sub-dimensions of that practice. In iterative rounds of coding, the codes, sub-codes, and their descriptions were revised (Miles, Huberman, & Saldaña, 2014) to more clearly reflect the specifics of the language used in the lessons. The codes along with their definitions and examples are included (Appendix E).

As shown in Table 10, each line of text was coded on the basis of whether it was a part of a conversational SET. Each line was then coded according to whether it was administrative, focused on the science content from the standard or science practices promoting that science content, not related to the science content of focus, unrelated to science content, a yes or no response, a clarification of what was said, or an interjection. Subsequently, each line that was focused on the science content from the standard, received a combination of dimension codes indicating what combination of dimensions the sentence referred to: the [DCI] disciplinary core idea, [SP-*] science practices (where the asterisk represented a code for each of the science practices), and/or [CCC] crosscutting concept. For each of the dimension codes, the line of dialogue received one or more sub-codes for that dimension. Each sub-code refers to a particular bullet point indicating the component of the practice, as described to be appropriate for middle school students in the NGSS.

Table 10. Example Application of Dialogue Codes to an Exchange from Lesson 3.1

Line	Dialogue	Set?	Topic	DCI?	SP?	CCC?	DCI sub	SP sub	CCC sub
645	Teacher: For example, if I'm on this side of the mountain versus this side of the mountain.	SET	S	DCI	SP-D	CCC	E	DG	CCC
646	You notice that this right here is kind of like a dividing line, right?	SET	S	DCI	SP-D	CCC	E	DG	CCC
647	Depending on which side of the mountain you are on, it's going to flow one way or the other, right?	SET	S	DCI	SP-D	CCC	E	DG	CCC

Note. DCI and CCC were applied if there was an indication of the DCI or CCC in the sentence. The SP code was applied when there was a reference to a science practice; the letter after the dash indicates which science practice, as many were incorporated at various parts of the lesson.

Development of Themes and Conjectures

In coding the lines of dialogue with the dimension-based codes, described above and illustrated in Table 10, it was observed that there were several different ways that lines with multiple codes could be presented in the classroom. For example, the lines in Table 10 are all statements. Despite the fact that lines 646 and 647 both end in question marks—with the phrase “right?”—each line is a statement about the content and is presented in a way for students to agree with. In addition to statements, three other contribution types were found and coded for: directions, prompts, and questions. It was also noticed that different lines of dialogue had different numbers of dimensions included, and different numbers of elements. To characterize the integration found in the dialogue, the lines were coded with each of those categories. The results showed patterns in the type, time, and activity associated with the integrated lines of text.

In the examples shown in Table 11, the teacher asks a question about slicing a clay model of a mountain in equal elevation slices so that the slice marks show all of the locations at a particular elevation, in the same manner as contour lines. The student’s response also references elevation, so both the question and the response statement were coded as referring to the DCI. Because the lines refer to the elevation of the clay model of a mountain, they earn a modeling code, and because they ask the students to analyze the number of equal elevation slices, they earn a data analysis code. Modeling and data analysis are both science practices, resulting in two dimensions in the statements, but three elements, the DCI and two SPs. The examples in Table

11 were also coded to show that they were part of a set, focused on science content, and did not include reference to the CCC. Those codes were left off the table to focus on the integration level codes.

Table 11. Example Application of the Element, Dimension, and Activity Codes to Lines of Dialogue

Line	Speaker	Dialogue	DCI?	SP?	# of Elements	# of Dimensions	Activity
355	Teacher	If I did a thousand feet, how many slices do you think I would have?	DCI	SP-M; SP-D	3	2	Question
356	Student	Zero, because no part of the mountain is a thousand feet.	DCI	SP-M; SP-D	3	2	Statement

Note. Each line received a DCI code because they refer to elevation, a modeling code because they refer to a clay model of a mountain, and a data analysis code because they refer to the number of elevation slices needed to represent the clay model.

Curricular Unit Codes

The codes developed for the video analysis were also applied to the prompts used throughout the curricular unit. The broad dimension categories, the sub-codes derived from the bullet points of the NGSS, and the integration codes were all applied to each individual curricular unit prompt, including the models and explanations used as homework assignments.

Representing an Example Lesson

As a result of the conversation analysis, lesson 3 was found to be particularly explicitly integrative, although it was designed to be implicitly integrative. As a result, lesson 3 was ideal for demonstrating how a lesson was enacted. It is represented to provide the reader with the opportunity to experience the pertinent full-class discussions, excluding the more procedural conversations. Discussions that are not purely logistical are shown in tables in this section, including a column with the conversation codes applied. Attention was paid to representing conversations that were particularly integrated, or not integrated. Any classroom activity not represented through conversation is summarized. Small-group conversations were at times also captured using the full-group or small-group video. Those conversations that were well captured are also represented. The full class period is represented from beginning to end.

Student Work – Conceptual Models and Science Explanations

The second research question, "Did students' expression of their integrated understandings change during the course of the unit?" was found to be best answered through an analysis of the students' understandings as represented through conceptual models and explanations of their understandings. The student work analysis consisted of six steps: (1) Data reduction to focus only on the data sources aligned with the research questions, (2) the development and application of a start list of codes to section 3 focal students' models, (3) the development of conjectures about integration of the dimensions and testing of those conjectures against the corpus of data, (4) the development and application of pattern-based codes representing the integration of the DCI, SP, and CCC throughout the student work, (5) themes developed on the basis of the conjectures across data types, and (6) themes revised and clarified with input from other researchers.

Data Selection

From all sections of the science class, students' models and explanations were collected, pre/post tests were completed, and in-class work was recorded. In one section of the course, students were interviewed, field notes were taken, and video was recorded during the class sessions. This one class section became the focus of the analysis of student work, because of the available record of classroom activities and student interviews, which allowed the triangulation of students' ideas. The focal students discussed their most recent models and explanations in each interview, which allowed these students' work to be triangulated across data sources (described below).

Development of Codes

The model codes were developed using the standard and the lessons as the basis for their development. Starting with the content dimensions, DCI, and CCC, the three main ideas for each dimension were listed, and a thorough representation of the concept and an incomplete representation of the concept were described. For each science practice, conceptual modeling, and scientific explanation, two levels of completeness were also described. The categories include a strong representation of the content, denoted with a plus (+); a weak representation of the content, denoted with a minus (–); or zero (0); there is no representation of the content. The three-level coding system was applied to all written responses, scientific explanations, and conceptual models. The complete coding rubric is shown in Table 12.

Table 12. Coding Rubric Used for Students' Conceptual Models and Scientific Explanations

		+	–	0
DCI				
	Elevation	Shows/states that elevation divides bodies of water AND water flows downhill	Shows/states that water flows downhill	Does not show/state cause or mechanism
	Infiltration	Shows/states water infiltrating into the ground with discussion of materials of mechanism	Shows/states water infiltrating into the ground without discussion of mechanism or material	Does not show/state cause or mechanism
	Water Cycle	Shows/states water cycling AND shows the sun as the mechanism	Shows/states water cycling without the sun as a mechanism	Does not show/state movement
CCC				
	Borders	Shows/states that elevation serves as a border to watersheds	Shows/states that watersheds have a border	Does not include a border or reference to a border
	Nested Systems	Shows/states that watersheds are nested in watersheds	Shows/states that watersheds are nested in watersheds	Does not include reference to nested systems
SP				
	Model	The model includes diagram with mechanism and labels.	(The model includes a diagram with movement AND explanatory text that tells instead of shows) OR (a diagram without sufficient text).	The model does not include movement.
	Explanation	The explanation includes claim, evidence, and reasoning that correspond to the scientific question.	The explanation includes claim AND (evidence that corresponds to the scientific question OR reasoning that relates to the scientific question).	The explanation includes only a claim or no information related to the scientific question.
		3	**2**	**0**
	Integration	Models that include a + or a – for DCI AND CCC AND SP	Models that include a + or a – for DCI OR CCC (AND SP)	Models that include NO + or – scores

Note. The categories are plus (+), the most complete representation, to minus (–), an incomplete representation, or zero (0), absent representation of the content. Each of the science practices also has stronger and weaker representations of the practice. Integration is based on the students' representation of the content while using a practice.

Development of Themes and Conjectures

While coding the models, it was observed that there were multiple ways that a single model or explanation could be classified as integrated. Because there were three categories each for the DCI and CCC, a student needed only to include a weak representation of the content in a weak representation of the practice to be classified as integrated. The integration spectrum of 3, 2, or 0 was based on the number of dimensions that the model or explanation integrated. It was found that a student needed to have at least a weak representation of the practice for the model or explanation to be categorized as integrated. Definitions or statements about the content provided a less complete representation of the student's understanding and might indicate that the student did not understand the content sufficiently to be able to describe it using the practice. As a result, both integration categories (2 and 3) require the model or explanation to include at least a weak representation of the science practice. This created a spectrum of integration ranging from a double weak (– –) integrated model or explanation to a triple strong (+++) integrated model or explanation.

Student Interviews

The student interview analysis consisted of six steps: (1) Data reduction to focus on only the interviews aligned with the research questions, (2) transcription of the audio files, (3) the application of the descriptive codes developed for the classroom discussion, (4) the application of the model and explanation based codes, (5) conjectures about integration developed from across data types applied to the interviews, and (6) conjectures revised.

Data Selection

After a review of all of the interviews, it was found that the first interview with students provided very little relevant information. The first interview occurred after lesson 1, in which students were entirely focused on how maps represent elevation information. Both the model and the explanation focus on how to represent elevation on a flat surface, which is what students describe in the interview, but students had not yet gotten to the movement of water, which meant that the information was not directly related to either research question. Therefore, the analyses focused on the second, third, and fourth (final) interview, in which students described models that represented the movement of water on or through the surface of Earth.

Transcription

All student interviews were transcribed, but, as described above, interview 1 was not analyzed. Filler words were not included in the transcription, nor were false starts. Each sentence was coded as a separate unit. A sentence was defined as a statement, so sentence fragments that were never completed, and yes or no responses, were coded as sentences. Sentence fragments were left as fragments.

Application of codes

Initially, the student interviews were coded with the discussion codes so as to identify instances of DCI, CCC, or SP in the interviews. This process showed where reference to the DCI, CCC, or SPs was made in the interview, but, like the coding for the classroom dialogue, these codes were applied for all references to the DCI or CCC, providing no indication of the accuracy of the reference. Therefore, the codes were not helpful in triangulating accuracy across the student work and interviews. This initial round of coding was used to provide a presence or absence code for the science practices of conceptual modeling and science explanation. The presence of the scientific explanation code signified that the student was talking about his or her model or explanation, or the process of developing the model or explanation. For instances coded with a DCI or CCC code, the accuracy rubric, used for the student representations, was used to indicate strong and weak understandings of the content. Using the same coding rubric across representations provided the opportunity to show alignment between the interviews and the models and explanations, in terms of the accuracy of the content.

Conjectures Developed and Revised

Integration of the three dimensions was determined at the response level and included all lines in which students discussed their model or explanation, including discussion of elements they thought about including in their models but did not. Conjectures were developed and revised relative to changes observed in the students' models over time, or relative to the difficulty that students had with a particular model or representation. Conjectures were also developed and revised relative to elements that did not change or that declined in students' models and representations.

Triangulation of Student Interviews with Conceptual Models and Explanations

For each student, a table (see Table 13) was developed to show his or her models and explanations over time. The table included all of the models and explanations, related to the concept of watersheds, that the focal students completed during the unit. The tables represent changes in individual dimensions as well as changes in the integration of students' responses across time and across representations. These tables were used to identify any differences in the way that students represented their understandings. In these tables, a zero score ("0") represents a dimension that was absent from the dimension; a minus score ("–") represents a weak understanding, often where the dimension was implied without being labeled; a plus score ("+") represents a thorough understanding, a dimension that is both represented in the model or explanation and labeled, or named in an interview (see Table 12, p. 55, for the full coding rubric). The full set of triangulation tables is included in Appendix F.

Table 13. Triangulation Table Showing One Student's Responses to Model, Explanation, and Interview Questions During the Unit

Student # 302	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	Integration				Integration				Integration				Integration			
	Type	Type			Type	Dimensions			Type	Dimensions			Type	Dimensions		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	2D	–	–	0					NOT	0	0	0				
Pre-Test	NOT	0	–	0					NOT	0	+	0				
Pre-Test	NOT	0	0	0												
Lesson 2 (2)	2D	–	+	0	3D	–	+	–	2D	–	+	0				
Lesson 3 (2)	3D	+	+	+	3D	+	+	+					2D	0	+	–
Lesson 4	2D	+	–	0												
Lesson 4	2D	–	–	0												
Lesson 4 (3)					2D	+	+	0	2D	+	+	0	2D	+	+	0
Lesson 5	2D	+	+	0												
Post-Test (4)	2D	–	–	0					NOT	0	–	0	NOT	0	+	0
Post-Test (4)	3D	+	–	+					2D	+	+	0				
Post-Test (4)	2D	+	–	0	2D	–	+	0								

Note. A plus (+) denotes a strong representation of the DCI, SP, or CCC, a minus (–) denotes a weak representation, and a zero (0) denotes an absent concept. Diagonal hashing indicates missing work or work not submitted. The numbers in parentheses after the assignment name indicate that the product was discussed in the interview of that number.

Validity

The internal validity (Miles, Huberman, & Saldaña, 2014) of the patterns was checked using multiple data sources for each of the types of assertions. For the classroom activity analysis, the analysis included the transcript of the full-classroom video, compared with the images from the video, and field notes taken by the researcher during the lesson.

Coding of interview students' understandings as represented using the rubric were also compared with the students' descriptions of their models from the student interviews. Six students participated in four interviews, discussing a total of five models and four explanations. An additional four students participated in two interviews, discussing two models and explanations. One interview from all students was not used because the content was not focused on the core disciplinary idea. All 10 interview students participated in the final interview, discussing their post-test model and explanation.

For the student work, the codes applied to the models were compared with the students' written scientific explanations and the student interviews; these tables were intended to triangulate (Maxwell, 2005, pp. 93-94) multiple data sources to show similar representations of students' understandings from a single time point (as shown in Table 13). During this process, any discrepancies between the data sources were noted and represented in the analysis. One significant discrepancy was that students appeared to show different understandings with conceptual models from those they represented with scientific explanations. This finding is further discussed in the section Conceptual Model/Explanation Pairs – Different Information From the Same Time (p.125).

Conceptual model and scientific explanation prompts varied throughout the unit, and no data were collected about the complexity of the questions. Therefore, longitudinal comparisons of students' understanding during the unit may not represent students' changing understanding over time, but may instead reflect variation in question complexity. It is likely that variation in the questions asked would mask much of the information about students' learning trajectories during the unit.

Reliability

The reliability of the codes was evaluated using inter-rater reliability and calculated using through the calculation of percent agreement. Two coders independently coded ten percent of each data type, with one coder coding the remaining ninety percent of the data. For the lesson codes, the inter-rater reliability was calculated to be 87% agreement. For the students' models, explanations, and interviews, the inter-rater reliability was calculated to be at least 80% for each data type. In addition, detailed examples of coding are represented in both the tables and in the appendices to allow the reader to be co-analyst of the data, demonstrating additional reliability of the coding scheme.

Limitations of the Study

This study is focused on a single case of the enactment of a curricular unit developed in collaboration with the teacher. In this particular context, the teacher spent a total of 3 years teaching science to each student. Therefore, he had previous teaching experience with two-thirds of the class. Some of the students had previously worked with a curricular unit focused on integrating science content with science practices. The analysis reveals how very different types of learners experience the curricular unit, highlighting how some of the more engaged students experience the unit very differently. Some students in the class were less engaged in the work, submitting few of the assignments, and some were absent for a large number of the class sessions. The descriptive results of students' work portrayed here do not represent the experiences of all of the students in the class. They represent the experience of students who attended most of the class sessions and turned in the majority of the assignments.

Although it was intended that the three student data sources (conceptual models, scientific explanations, and student interviews) would provide an opportunity to triangulate students' understanding at one particular time period, each data source provided a different representation of the students' understanding. Together, these three sources may provide a more complete representation of the students' understanding, but, most likely, the model and explanation's different question prompts led to students' contributing different representations, and ultimately the students described only particular elements of their conceptual models and explanations in the interview, focusing on a selection of the details.

In the analysis of the data, the focus was on sentence-level coding. Although this did capture some integration, it is expected that more integration would be captured using a different grain-size approach. In the results, an example of integrative conversation is shown, but the grain size of the analysis made representing these integrative conversations difficult. In future research, it would probably be more effective to focus on discussion topics or activities as a way to segment the classroom conversation.

In analyzing the data, the CCC was included as an entity separate from the DCI, but in fact, inclusion of a thorough representation of the CCC was dependent on a thorough understanding of the DCI. This relationship was not true for the reverse relationship: having a deep understanding of the DCI was not dependent on knowledge of the CCC. Therefore, although it appears possible to have a thorough understanding of the CCC without knowledge of the DCI, it was not possible in a practical sense.

In representing the results of the analysis of the pre- and post-test data, the data were simplified into a single quality code for the DCI, SP, and CCC of each student's conceptual models. Two conceptual models were analyzed to produce these results, and the highest code was used to represent the students' understanding for each dimension. As a result, the integration is a representation of how a student represented the three dimensions across two conceptual models, and it could result in an inflated level of integration. This does not hold true for the scientific explanations, as only one scientific explanation per student was analyzed from the pre- and post-test.

Chapter 4
Results

Summary of Prior Chapters

The purpose of this research was to investigate the opportunities for students to learn to integrate the three dimensions of science education outlined in the *Next Generation Science Standards* (*NGSS*), and the ways that students do or do not represent an integrated understanding of the concept in their representations. This research was guided by the following research questions:

- In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?
- Did students' expressions of their integrated understandings change during the course of the unit? If so, in what ways did their expressed understandings change?

The results presented in this chapter are based on the analysis of classroom video transcripts, field notes taken during section 3 class sessions, the class work submitted by students in section 3, pre- and post-tests completed by all students in section 3, and interviews with 10 students in section 3. The analysis of these files is described in detail in Chapter 3, but it can be summarized as the development of codes and coding rubrics in alignment with the performance expectation, and the development of conjectures based on patterns in the application of codes.

Introduction

Framing the Chapter

This chapter answers the two research questions by first showing students' opportunities to integrate the three dimensions in the written curricular unit and in the classroom dialogue, and second represents students' changing understandings during the unit. The chapter begins with an overview of the opportunities to integrate in the written curricular unit, and it shows how the enacted curricular unit provided opportunities different from those originally intended. Next, the dialogue from the classroom discussions is analyzed to show the lesson in which the most integrative discussion took place. Specific attention is paid to lesson 3, where students had the most opportunities to integrate the three dimensions in class. The integrative moves the teacher made during the class are represented using examples of the integrative dialogue from lesson 3. The students' changing understanding is represented, first through a broad overview of the changing representation in the pre-test and post-test, and then by looking at specific representations and how they afforded different opportunities for students to represent their understanding. The chapter closes with the case of two students' learning during lesson 3, and representations throughout the unit. Finally, the results are reconsidered, focusing on how they inform our understanding of the research questions.

Students' Opportunities to Learn an Integrated Understanding During the Curricular Unit

Opportunities to Integrate From the Written Curricular Unit

The curricular unit was almost entirely written before its enactment. Exceptions to this include an additional lesson on infiltration and ground water, and the removal, after the enactment began, of a lesson that required students to find the size of a watershed (both lessons are in Appendix A). The curricular unit as a whole was designed to support students' development of an integrated understanding of the content, but the dimensions that the written curriculum supported were analyzed only after the curricular unit was enacted, in conjunction with the other analyses described here. Therefore, this analysis is included in the results section and described in the following sections.

Design of the Written Curricular Unit

The curricular unit was developed with the intention of supporting students' integration of the three dimensions of science education (disciplinary core idea [DCI], science practice [SP], crosscutting concept [CCC]) through framing the curricular unit around a particular water system, watersheds. Most of the questions in the curricular unit explicitly include only two of the dimensions, as shown in Figure 3. The few questions that explicitly asked students for one dimension were somewhat distributed throughout the curricular unit, with most occurring between the beginning of the third lesson and the beginning of the seventh lesson. Three questions explicitly asked students to integrate three dimensions—one explanation prompt in lesson 2, and a model and an explanation prompt in lesson 9. The students' work from lesson 9 was not collected, so those responses were not analyzed. The remainder of the model and explanation prompts explicitly included two dimensions in the question prompt, as shown in Figure 3.

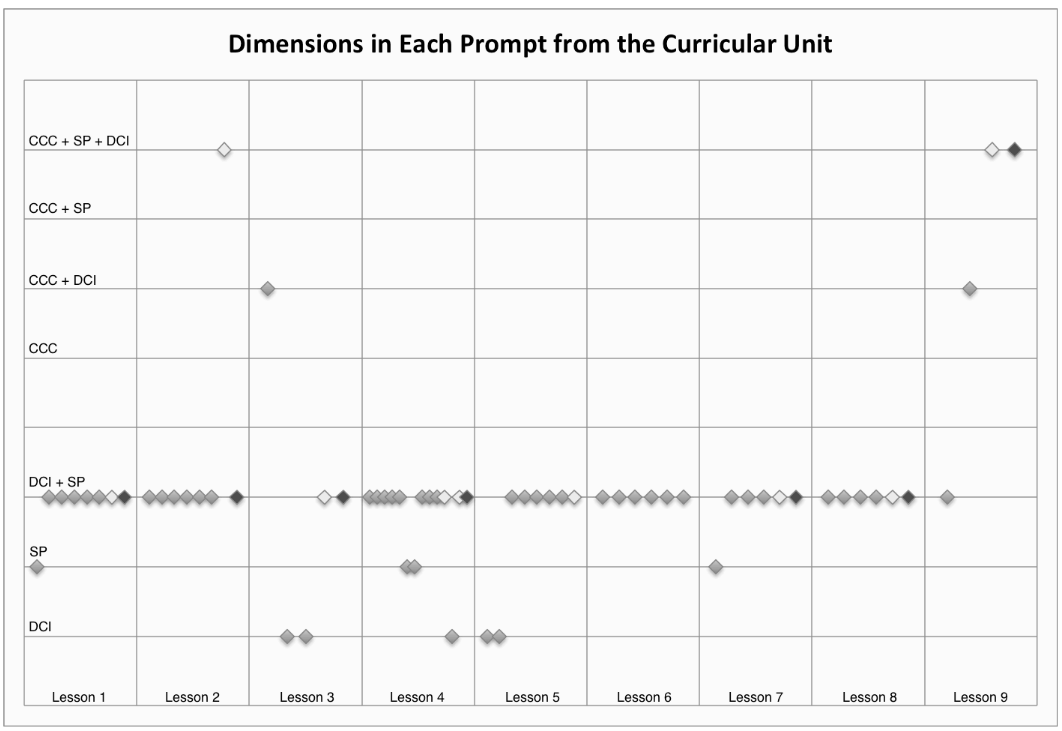


Figure 3. Question prompts from throughout the curricular unit, by lesson, coded according to the dimensions included in the question prompt. Conceptual model prompts are white. Scientific explanation prompts are black. Questions that guided students through the curricular unit are gray.

The distinction between explicit and implicit is made here because some prompts asked students to include two dimensions, such as, "Draw a model showing what influences how big a watershed can be.” This prompt explicitly includes both the water in Earth’s surface processes and the SP of drawing a conceptual model. This question also implicitly includes the CCC. To answer this question, a student might also consider what determines where the boundary of a watershed is located, wherein a boundary of a system is one component of the CCC, thereby implicitly including the CCC. Implicit inclusion of a component was not coded for, because students had to make a connection in order to be prompted to include the implied component.

The initial design of the curricular unit included the models and explanations as synthesis components of each lesson. The prompts were intended to serve as a formative assessment of the students’ current understanding of the concepts, and also as an opportunity for the students to bring together their new and older understandings of the concept. In lesson 4, students explored the interactions between water and Earth’s surface. This lesson followed lessons that focused on how water moved on Earth’s surface, moving students toward an examination of water below the surface. One of the lesson 4 synthesis questions, a conceptual model, prompted students to “draw a model of how water interacts with Earth’s surface in a watershed.” This prompt brought together students’ knowledge of the movement of water in watersheds (the focus of the first three lessons) with students’ knowledge of the movement of water with the surface materials (the focus of lesson 4). After this lesson, the prompts became more focused on synthesizing the activities from the lesson and less focused on making connections across lessons. The explanation prompts did not have as clear a shift in their focus. The model and explanation prompts used throughout the curricular unit are listed chronologically, along with the dimensions integrated in the prompt, in Table 14.

Incorporation of the Science Practices Into the Enacted Curricular Unit

Each lesson, which often spanned multiple class periods, included investigation activities. Students’ investigations were supported through the use of short-answer questions, which the students had to respond to on paper—the gray dots in Figure 3. Over the course of the lesson, the questions prompted students to make connections between the DCI and SPs, or DCI and CCC. It was intended that the classroom activities would begin with the knowledge-building investigations, which students would begin to synthesize through a class discussion, and would subsequently create the synthesis products of a conceptual model and scientific explanation. Because the class periods were 100 minutes long, which is the length of two class periods in many schools, activities that would traditionally take 2 days were completed in one class period.

This left the class with an insufficient amount of time to synthesize at the end of the session. Therefore, the synthesis activities were assigned as homework. At home, students completed models and explanations for homework, and the synthesizing discussion took place during the following class period.

Table 14. Complete List of Model and Explanation Prompts in the Written Curricular Unit

Lesson	SP	Prompt	Dimensions
1	Explanation	Write a scientific explanation that answers the scientific question: Can the 3-dimensional landscape be represented by a 2-dimensional model?	DCI + SP
2	Explanation	Write a scientific explanation that answers the scientific question: What makes an area a watershed?	DCI + SP
3	Explanation	Write a scientific explanation that answers the scientific question: How big can a watershed be?	DCI + SP
4	Explanation	Write a scientific explanation that answers the scientific question: What factors influence the flow of water on the surface of Earth?	DCI + SP
7	Explanation	Write a scientific explanation that answers the scientific question: How does water impact the landscape?	DCI + SP
8	Explanation	Write a scientific explanation that answers the scientific question: Which types of water do humans impact in a watershed?	DCI + SP
9	Explanation	Write a scientific explanation that answers the scientific question: Is a watershed a system?	DCI + SP + CCC
1	Model	Draw a model of how 3-dimensional objects can be represented on a two-dimensional paper.	DCI + SP
2	Model	Draw and label an illustration (a conceptual model) showing how water moves within a watershed. Make sure to include what influences where the water goes, and what defines the borders of a watershed. This should be your own example, do not draw the same thing that was in class.	DCI + SP + CCC
3	Model	Draw a model of a watershed. Make sure to include what influences how big the watershed is and what influences where the water goes.	DCI + SP
4	Model	Draw a model of what you think is happening with the water and the surface materials. Make sure to include the ways in which the materials are different from one another, making the results different.	DCI + SP
4	Model	Draw a model of how water interacts with Earth's surface in a watershed.	DCI + SP
5	Model	Choose a type of landscape (write the type of landscape at the top of the page), and then draw a model of how water interacts with the layers of surface material in that type of landscape.	DCI + SP
7	Model	Draw a conceptual model of how the water interacted with the physical model of the watershed.	DCI + SP
8	Model	Draw a model of how pollutants interact with a watershed.	DCI + SP
9	Model	Draw a model that shows why a watershed does or does not count as a system.	DCI + SP + CCC

Note. The right column lists dimensions explicitly included in the prompt.

These structural changes seemed to affect the students' learning. Because the conceptual models and scientific explanations were done as homework, interactions with parents seemed to reinforce the notion that the students should have the right answer on their homework. This is contrary to one of the goals of the activities—to develop students' understanding through a synthesizing activity. Several students discussed looking up the "right answer" or asking a parent about the "correct answer." The assignments were intended to represent the students' current understanding of the phenomenon, as a formative assessment that would help the teacher understand which areas of the concept of watersheds needed further development. Because these synthesizing activities were assigned as homework, students had a wider variety of resources to draw from, including the internet and parents.

Although the synthesis responses were intended to serve as formative assessments of students' understandings, in the end they were not used that way. Students received no individual feedback relative to their models, and they received very little group feedback about what should be changed to improve their responses. No improvement was seen in the students' use of SPs in their responses to the explanation and model prompts over time (see Appendix F for tables of student work and interview response coding).

Summary of the Opportunities to Integrate From the Written Curricular Unit

The curricular activities and homework prompts provided students with opportunities to integrate two dimensions, but few opportunities existed to integrate three dimensions. Several questions included implicit opportunities to integrate the third dimension (CCC) into the response, but they did not explicitly refer to the CCC. Most of the model and explanation questions were assigned as homework. Because we did not see students complete these assignments, we cannot know what kinds of resources they used. One clear opportunity to integrate the three dimensions occurred in the lesson 9 model and explanation questions, each of which had a three-dimensional prompt, but these were not collected from the students in section 3 and therefore could not be analyzed.

Opportunities to Integrate From the Classroom Dialogue

Students were supported in making sense of their in-class experiences through classroom discussion, and through directions and help from the teacher in completing the class activities. The sense-making discussions in class generally occurred in the lesson following the activities, with students completing the models and explanations in the evenings between lessons. These discussions were largely teacher focused—that is, the teacher guided the discussion by asking targeted questions to guide students' thinking, but students' contributions tended to be short, single-word responses. In two lessons (lessons 3 and 9), the CCC was most explicitly included into the classroom dialogue (Figure 4). One clear difference between these lessons is that in lesson 3, the CCC is incorporated into the conversation as a third dimension, whereas in lesson 9, the CCC is discussed outside the context of the DCI. In lesson 3, the teacher, and in one case a student, made moves to integrate the dialogue in the classroom discussion.

Integrating the CCC Into Dialogue Throughout the Unit

Although bi-dimensionally integrated sentences incorporating the DCI with a SP were found throughout the unit, it was more rare to find those that included the CCC (Figure 4). The explicit inclusion of the CCC did not inherently mean that the sentence was tri-dimensionally integrated. In many instances, the CCC was discussed alone or integrated with only the DCI (integration of the CCC with a SP without the DCI was not observed). In only three lessons (seven class periods) was the CCC incorporated. Lesson 3, in which students built a working definition of a watershed based on their analysis of elevation data in topographic maps, included a large portion of the dialogue. Only eight statements in lesson 4 included reference to part of the CCC, and all but one of these references were about a watershed being "divided by elevation"—a part of the definition developed in lesson 3. The one other reference explicitly stated that watersheds are "full of a collection of sub-watersheds," referring to nested systems. Lesson 9, the final lesson in the unit, was developed to help students make connections between what they learned and the concept of systems. Using the definition of a system taken from *NGSS*, students created models and explanations showing why a watershed could be classified as a system.

Less common than the inclusion of the CCC into the dialogue was dialogue that was tri-dimensionally integrated (Figure 5). This dialogue is a subset of the dialogue lines presented in Figure 4). The lines of dialogue that make up Figure 5 are only those that were plotted on unit 3 of the y-axis in Figure 4, representing the inclusion of all three dimensions. In Figure 5, the y-axis represents the type of dialogue, 1 represents a question, 2 a statement, and 3 an activity prompt; 4 (absent from the figure) represents giving directions. Also separated are the lines that the students contributed to the whole class discussion (red) and the lines the teacher contributed to the discussion (blue). Because Figure 5 is a subset of Figure 4, the dialogue occurred only in the same lessons in which we saw the CCC, and much less frequently than the inclusion of the CCC. Most of the data points represent statements, with a few teacher-initiated questions and one student-initiated tri-dimensional question. These conversations are further investigated in the analysis of the types of conversation below. Many of the examples highlighted in the analysis are taken from lesson 3 because it had the greatest concentration of tri-dimensional dialogue.

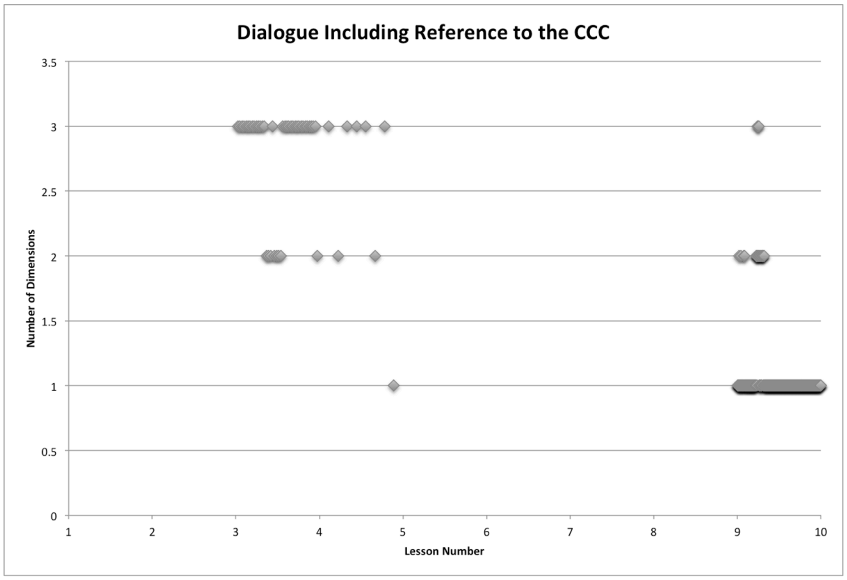


Figure 4. Dialogue from all lessons that includes reference to the CCC. Each point represents one sentence that included reference to the crosscutting concept. All instances fell in one of three lessons (lesson 3, 4, or 9). All instances of one dimension represent the CCC; all instances of two dimensions include the CCC and DCI.

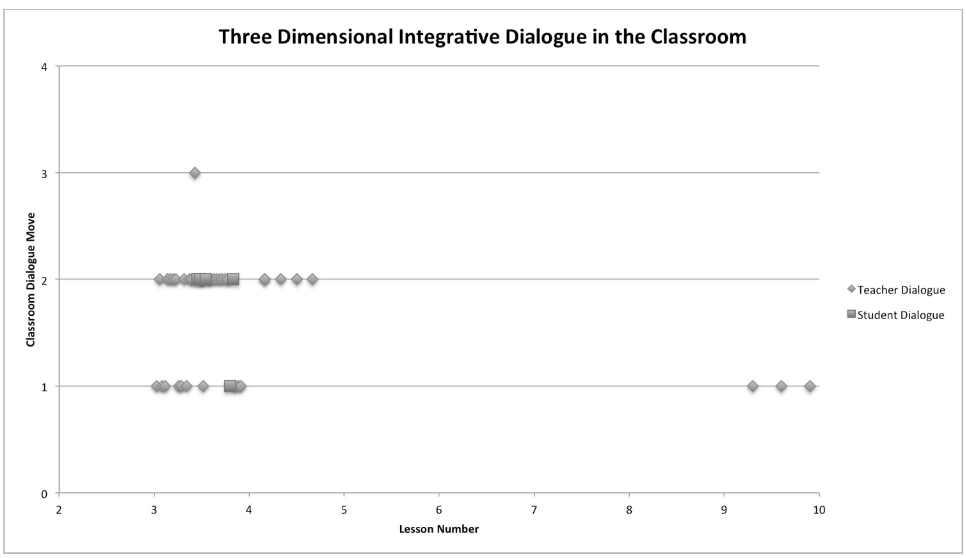


Figure 5. Dialogue from all of the lessons that includes all three dimensions (DCI, SP, CCC) in one sentence. Each data point represents a single sentence. All instances fell in one of three lessons (lesson 3, 4, or 9). Dialogue spoken by a teacher is represented with a diamond; dialogue spoken by students is represented with a square. The y-axis represents the dialogue move made by the speaker: 1 denotes a question, 2 denotes at statement, 3 denotes an activity prompt, and 4 (absent from these lines) denotes giving directions.

In the enactment of the lessons, integrative lines were incorporated into the class in particular patterns. None of the classroom conversations were planned, meaning that the three dimensions were spontaneously incorporated by the teacher and students into the classroom discussion. The ways that the teacher incorporated integrative conversation into the classroom dialogue fell into four categories: directions, activity prompts, questions, and statements. All lines of dialogue that included more than one dimension were coded to describe the way in which the dialogue was integrated. Some examples, taken from lesson 3, the most integrated lesson, are shown below, with coding to show the dimensions being integrated in the dialogue.

Activity Prompts

One category of teacher moves represented the teacher's use of the integrated activity prompts in the lesson dialogue. In other words, the teacher was reading the text of the curricular unit questions. This was a fairly infrequent occurrence, and it only once occurred with tri-dimensional integration (see Figure 5), which is not surprising as the vast majority of prompts were bi-dimensional (see Figure 3, p. 64).

Table 15. Dialogue Where the Teacher Includes Language From One of the Written Curricular Prompts

Speaker	Dialogue	Dimensions
Teacher	Which maps have elevation, the height of the landscape, represented on the map?	DCI – Elevation SP – Data Analysis
	On that first question, I want you to respond with which maps you feel represented elevation or height above ground level, on that piece of paper.	DCI – Elevation SP – Data Analysis
	Number one, which maps represented heights in the elevation?	DCI – Elevation SP – Data Analysis
	I would like you to use full sentences. (Lesson 1, lines 400 & 401, 411 & 412)	

As shown in the example in Table 15, instances of this code were often preceded or followed by directions on the kinds of information that were expected to accompany the response. When referring to a model or explanation prompt, directions were often included that showed what a complete response looked like. When the teacher was not directly reading the prompt, the instance was classified as giving integrated directions.

Directions

In the classroom dialogue, the teacher often needed to provide the students with information required to complete the assignment. Each lesson was structured, primarily, around a set of questions that the students had to complete while doing an investigation. The investigations took a number of forms, one of which was analyzing elevation data from topographic maps to predict the direction of the flow of water. Students struggled with this activity in lesson 2. At the end of lesson 2, students said, for example, "[Teacher], I can't tell the rivers apart." Or, when describing how topographic lines show the direction of water flow, "'Cause it would follow the lines… I don't know how to say it." Students struggled to describe how the flow of water related to the topography. As a result, the teacher added an activity focused on predicting the flow of water. The students had previously represented areas of high and low elevation on a map, but this time their sole focus was on making the predictions. The activity was designed by the teacher to make a connection between the contents of lesson 2 and lesson 3. (For a detailed description of the activity, see the section titled, Predicting Water Flow Using Models of Elevation (p. 85).) In the directions, the teacher explained that students needed to "draw arrows representing where water would flow based on elevation." It had already been stated that water will "go down." So students were being asked to analyze the maps to determine the slope of the landscape using the elevation data on the map. Students then used arrows to represent movement from high to low elevation. An example of a map created during this activity is shown in Figure 6, the class map, where the purple arrows show the downhill movement of water based on the black, upside-down-V mountains.

Table 16. Dialogue Where Students Are Given Directions About Developing Integrated Representations

Speaker	**Dialogue**	**Dimensions**
Teacher	There's a lot of rain coming down. If rain were to fall on your map [data analysis], right here. Using your ideas of elevation because what will happen [prediction] with elevation and rain [downhill flow of water]?	DCI – Water Flow SP – Data Analysis SP – Explanation: Prediction
Student	It will go down [downhill flow of water].	DCI – Water Flow
Teacher	It will hit something, and based on how high or how low it might be in terms of elevation, it might flow a certain direction [downhill flow of water] right? And that was part of your homework. To figure out how do you explain where water flows if it happens to hit a certain landscape[?] What I want you to do with your other color, not the black marker, but your other color now. Is to draw arrows where water would flow based upon elevation [data analysis]. Where would you see water flowing? Where would it go? Which direction? So on your map, figure out which way water would flow [prediction]. (Lesson 3.1, lines 258-271)	DCI – Water Flow SP – Data Analysis SP – Explanation: Prediction

In giving the directions for this activity (Table 16), the teacher brought together two SPs—data analysis and making predictions—with the DCI, the role of water in Earth's surface processes. In giving the directions, the teacher implicitly included information about the mechanism of the flow of water—the force of gravity—by describing that water flows downhill. In this way, the teacher's directions implicitly included all of the information the students needed to perform the activity. Later in the lesson, the teacher used the students' predictions for the flow of water to explicitly identify the location of dividing lines for the flow of water.

Statements

The majority of tri-dimensional lines from the classroom dialogue were integrative statements made by the teacher (see Figure 3), which indicates that much of the work of integrating the conversation in the full-class discussions was not being done by the students. Not all of the integrative work occurred during full-class discussions; students responded to bi-dimensionally integrated prompts and held frequent small group conversations throughout the unit.

In the dialogue represented in

In these statements, the teacher modeled using a topographic map to make predictions and analyze data about the movement of water on the surface of Earth. The teacher's statements both integrated and explained the content in the context of the CCC and SP. This was not an example of the students themselves integrating, but of the teacher modeling integrative thinking for the students using integrative statements.

Table 17, **Error! Reference source not found.**the teacher modeled integrative thinking by making integrative statements, supporting students to make connections between the DCI, SP, and CCC. This dialogue was part of the class discussion in lesson 3.1. This segment of dialogue concluded a modeling activity in which the teacher analyzed elevation data to predict the flow of water on a topographic map (Figure 6). The teacher built on the prediction data to locate areas where water flowed in two different directions. Part of the dialogue, in which the teacher helped students to identify these areas, is represented in

In these statements, the teacher modeled using a topographic map to make predictions and analyze data about the movement of water on the surface of Earth. The teacher's statements both integrated and explained the content in the context of the CCC and SP. This was not an

example of the students themselves integrating, but of the teacher modeling integrative thinking for the students using integrative statements.

Table 17.**Error! Reference source not found.** These division points are shown in Figure 6 in the lighter colored pen; the lines represent watershed boundaries, which the teacher connected to make roughly circular watershed boundaries. (For a more detailed discussion of this activity see the section titled Predicting Water Flow Using Models of Elevation.)

After locating the watershed boundaries, the teacher described the evidence for the watershed boundaries' locations. In this conversation, the teacher is at different times implicitly or explicitly describing the elements of the CCC that contribute to our understanding of the location of watershed boundaries. For example, in line 693, the teacher said, "Even though the mountain splits it, guess what happens…they get reunited and go back into Washington River." In this statement, the teacher explained both that elevation serves to split water, sending it downhill to different locations, and that on close examination of this geography, the water ultimately goes to the same water body. This is an implicit example of nested systems, where multiple creeks' watersheds, coming from the mountains, feed into the same river watershed. Later, line 698, the teacher explicitly linked the conversation back to watershed boundaries.

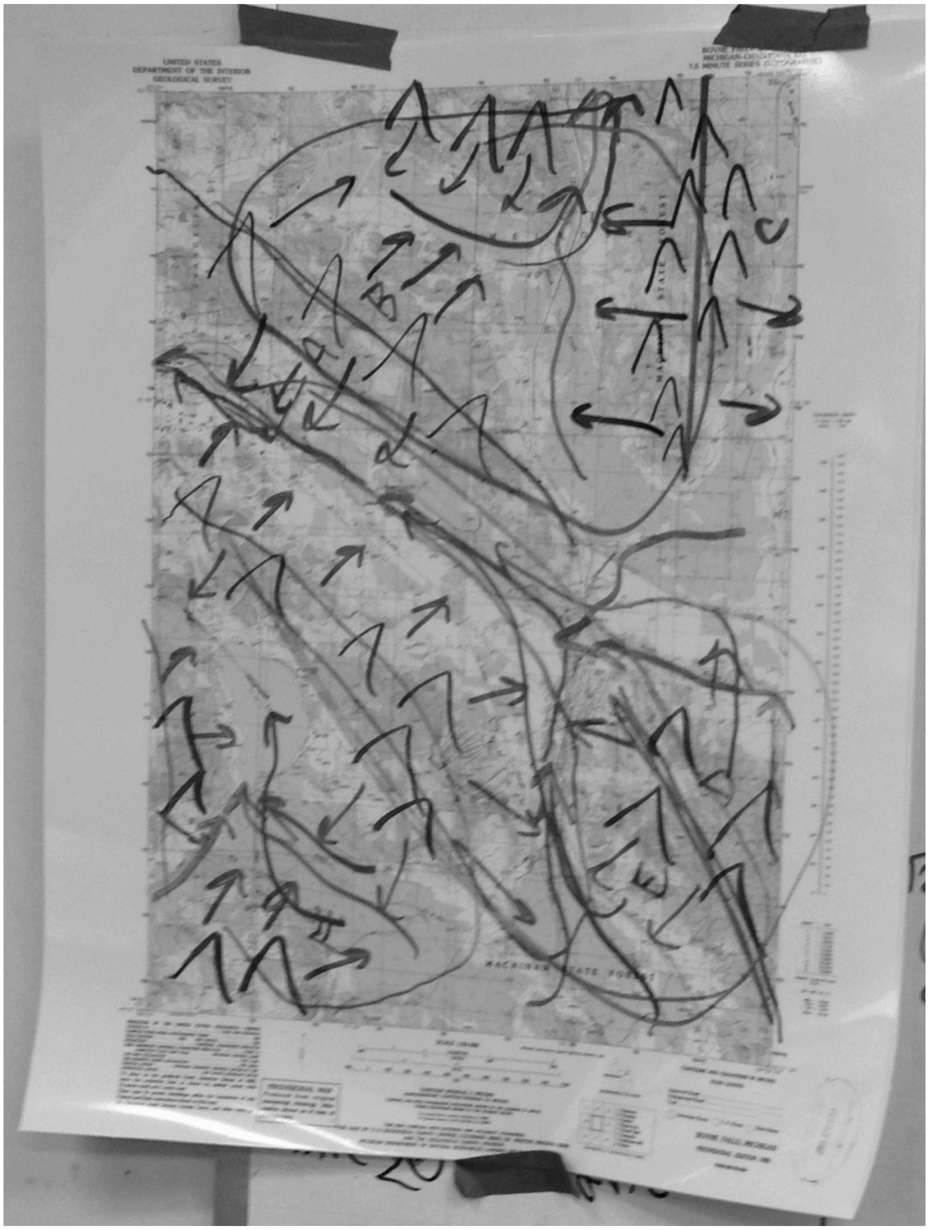


Figure 6. The annotated map showing the paths of the water and the paths of water drops A through F. Lighter colored lines indicate dividing lines created by the areas of high elevation.

In these statements, the teacher modeled using a topographic map to make predictions and analyze data about the movement of water on the surface of Earth. The teacher's statements both integrated and explained the content in the context of the CCC and SP. This was not an example of the students themselves integrating, but of the teacher modeling integrative thinking for the students using integrative statements.

Table 17. Example Where the Teacher Integrates the Dimensions Through an Integrated Example

Speaker	Teacher Dialogue	Dimensions	Activity
Teacher	These mountains figure out which way water is going to flow.	DCI – Water Flow SP – Data Analysis	Statement
	Same thing with this watershed, right?	DCI – Water Flow SP – Data Analysis	Statement
	If I look at this map, there's a watershed right here because all of this stuff flows into a creek, which flows into a river that goes out this way.	DCI – Water Flow SP – Data Analysis	Statement
	That flows this direction.	DCI – Water Flow SP – Data Analysis	Statement
	Here I have another watershed.	DCI – Water Flow SP – Data Analysis	Statement
	Oops.		
	Kind of like this boundary right here.	DCI – Water Flow SP – Data Analysis CCC – Boundary	Statement
	This is a horrible map now but hopefully you get the idea that even though this mountain splits it, guess what happens.	DCI – Water Flow SP – Data Analysis	Statement
	They get reunited and they go back into Washington River.	DCI – Water Flow SP – Data Analysis	Statement
	This is another watershed.	DCI – Water Flow SP – Data Analysis	Statement
	Here we have our own little watershed because this stuff doesn't go into the other rivers.	DCI – Water Flow SP – Data Analysis	Statement
	It goes into this lake and goes out that way.	DCI – Water Flow SP – Data Analysis	Statement
	Can you see how the boundaries kind of tell us which way the water is going to go?	DCI – Water Flow SP – Data Analysis CCC – Boundary	Question
	(Lesson 3.1, lines 686-698)		

Note. During this dialogue, the teacher was at the front of the room showing students how to locate watershed boundaries on a topographic map. The resulting map is shown Figure 6.

Questions

The teacher used questions to promote discussion in the classroom in several ways. While explaining content to the students, he often incorporated questions into the dialogue that students were not expected to answer, questions that seemed to be intended to promote student thinking. For example, early in lesson 3.2 (lines 226-228), the teacher said, “So, if we look at the definition, what's the area of land? The area of land is what we see here outlined. Is it connecting to a large body of water?” Students did not answer either of these questions, and the teacher continued to present new material.

In other circumstances, the teacher used the questions to promote a discussion in the classroom—for example, several lines later the teacher moved to clarify a student’s question.

“Now, [305]'s question before, do you name [a watershed] after the land or do you name it after the water?” (Lesson 3.2, line 236) A little later, the teacher revisited a question raised by a student the day before. In response to an indication that she was still confused, the teacher engaged the whole class in a check for understanding (Table 18). After this initial check, students were asked to explain their position, turning what could initially be considered a check for understanding into an episode of argumentation.

Table 18. Example of Argumentative Questions Asked by the Teacher

Speaker	Dialogue	Dimensions
Teacher	The Atlantic ocean all around here, does it have a watershed?	DCI – Water Flow SP – Argumentation
	How many people by a show of hands believe that the Atlantic Ocean has a watershed?	DCI – Water Flow SP – Argumentation
	How many people do not believe that the Atlantic Ocean has a watershed?	DCI – Water Flow SP – Argumentation
	How many people do not know if the Atlantic Ocean has a watershed?	DCI – Water Flow SP – Argumentation
	Lesson 3.2 (lines 298, 304, 308 & 309)	

Many questions, including those the teacher posed while explaining content, could have been taken up as argumentation, but only a few stuck and were pursued. Those that were pursued were largely initiated by students, because the teacher posed questions quite regularly, whereas only those students’ questions that were responded to were taken up for a more thorough discussion. The question about whether an ocean could have a watershed was one that was revisited multiple times during lessons 3.1 and 3.2. Ultimately, whether these instances of discussion about the question serve as an example of argumentation is unclear. In many of the class discussions about content, the teacher served as a consistent intermediary in the discussion, thus serving also as an arbiter of accuracy.

Whether the dialogue serves as a good example of argumentation is open to interpretation. Elements of argumentation are there—an open question with back and forth discussion of two perspectives on a solution—but the discussion is mediated by the teacher, who validates the accuracy of the points. This would be a clearer example of argumentation if the students were discussing among themselves, and if validation of points were based on the available evidence. Therefore, these examples seem to be the beginnings of argumentative discussion in the classroom. The initiation of the discussion was often based on questions posed by the teacher taken up by the students.

A Combination of Codes – Integrative Discussion

As previously mentioned, the conversations in the classroom were not planned. The teacher used the activities as a shell from which he developed discussions that supported students in their engagement with the investigations. There were relatively few instances of tri-dimensional lines of dialogue in the unit, as shown in Figure 5 (p. 69). Lesson 3 was the clear exception, with a fairly high concentration of tri-dimensionally integrated lines. From this lesson, a few examples of integrative discussions can be cited. These integrative discussions are examples of the kinds of conversations that did take place during that one lesson. The two conversations represented below focus on the same topic—whether an ocean has a watershed. In both conversations, student 311 expressed confusion about whether an ocean can have a watershed. In the first example (Table 19), the teacher pursued the explanation without probing why the student was confused; instead, he made explicit the components of a watershed and why an ocean fit within that definition.

Table 19. Example Dialogue Where Student Engages in Argumentation Involving Content

Speaker	**Dialogue**	**Dimensions**
Teacher	What's the largest example that will fit this definition? Okay? And obviously a lot of people are thinking about what as large bodies of water?	DCI – Water Flow
Student	Ocean.	DCI – Water Bodies
Teacher	Oceans.	DCI – Water Bodies
311	But they're not.	SP – Argumentation (Claim)
Teacher	But the oceans. The word ocean is not the watershed right? 'Cause it has to be, it has to be an area of land. But in this definition of watershed is there an idea that ocean will fit into?	DCI – Water Bodies SP – Argumentation
302	Yeah.	
Teacher	What?	
302	A larger body of water.	DCI – Water Bodies
Teacher	Larger bodies of water could be replaced by ocean. Area of land where water flows into an ocean divided by elevation. Is there an area of land that is going to flow water into the ocean?	DCI – Water Bodies, Water Flow, Elevation SP – Argumentation (Counter Argument) CCC – Outputs, Boundary
Student	Yeah.	
Teacher	That's what you need to help explain to us. What that area of land is. (Lesson 3.1, lines 852-870)	DCI – Water Flow

This conversation is part of the group answer for one of the investigation questions, "What do you imagine is the largest watershed you can find?" Earlier in this lesson, the class developed a group definition for a watershed: "an area of land where water flows into larger bodies of water, divided by elevation." Here, the teacher inserted the word "ocean" into the definition as he set up an activity for students to find the watershed for an ocean. In a subsequent class period, lesson

3.2, this point was not fully clarified, and student 311 brought it up again (Table 20). This time, she initiated a conversation about a particular point that she found confusing about the Atlantic Ocean having a watershed. The manner in which she brought up the question revealed that something about the destination of the water made it confusing. She began, “I thought, does everything flow out?” At this point, it was unclear whether her confusion was about nested systems or the outputs related to a watershed, as both are components of the CCC. Her next contribution made it clearer: “Yeah, but are those watersheds of their own? Just going into something bigger, I guess?” The teacher took this comment as being related to nested systems and followed up by giving examples of watersheds (systems) that fall within larger watersheds, although he didn’t explicitly demonstrate that each watershed is larger than the previous one listed.

These conversations are examples of class discussions in which the three dimensions were integrated. Although the first discussion had an instance in which all three dimensions were integrated (i.e., the definition), the second discussion seems to better clarify the concept. The latter includes clear links to two elements of the CCC—nested systems and outputs. These conversations in which multiple dimensions are integrated in a short period of time also seem to help students develop and integrate understanding of the concept, potentially more so than the integrated definition of watershed. It is through the connections in individuals’ ideas in a conversation that the dimensions become integrated in this example.

Table 20. Example Dialogue Where Participants Build Integration and Student Asks Questions Related to the Crosscutting Concept

Speaker	Dialogue	Dimensions
Teacher	But remember, we're talking about the Atlantic Ocean watershed, are there things that are connected to it?	DCI – Water Bodies
Student	Yes	
Teacher	That fill the definition.	
311	I thought does everything flow out?	CCC – Outputs
Teacher	It's going to flow out but eventually we get to the oceans. Where it kinda like the last point.	CCC – Outputs DCI – Water Bodies
Student	Yeah	
Teacher	I guess your idea of it connecting to something else. It's kinda like that last stop of the whole thing. Right. Everything kinda flows from watershed into eventually the ocean. That's kinda we're at the end. I think that's where are stop. But from that end point is there something that connect into that flood into.	CCC – Outputs DCI – Water Bodies
311	Yeah, but are those watershed of their own? Just going into something bigger I guess?	CCC – Nested Systems SP – Argumentation
Teacher	Are those watershed going into something bigger. Let's think about it. Does the Huron connect to something larger?	CCC – Nested Systems
Student	Yeah	
Teacher	Does the Lake Eire watershed connect into something larger?	CCC – Nested Systems
Student	Yeah	
Teacher	Right.	
	(Lesson 3.2, lines 359-381)	

Summary of Opportunities to Integrate From the Classroom Dialogue

Most of the opportunities to integrate from the classroom dialogue were instances of integration of the DCI with the SP. Opportunities to integrate the CCC or all three dimensions were much less frequent. In lessons 3 and 4, the CCC was incorporated into the conversation quite a few times as a third dimension being incorporated with the DCI and SP. In lesson 9, the CCC was the topic of discussion, serving as the only dimension in quite a few lines of dialogue. Most of the instances of three-dimensional integration were statements made by the teacher during full class discussion. On a few occasions, students contributed tri-dimensionally integrative statements. A few instances of tri-dimensionally integrative questions existed in lessons 3 and 9, and one instance of a tri-dimensionally integrative activity prompt was found in lesson 3. The most fruitful opportunities seemed to be integrative conversations, but these were not well captured using this unit of analysis.

Opportunities to Integrate From the Enacted Curriculum

To illustrate some of the conversations and activities that took place as part of the curriculum, this section provides a detailed description of the activities and conversations that occurred as part of the first day of lesson 3. Lesson 3 was selected because it was during this lesson that a large portion of the integrative conversations and activities took place. Many of the examples of dialogue and student work that follow in this chapter are based on this lesson. Therefore, it is hoped that this detailed description of the lesson will provide a frame for understanding the additional examples described later in this chapter.

Lesson 3, Day 1

Lesson 3 built on students' experience in the previous lesson (lesson 2), in which students gained experience interpreting and analyzing topographic maps to determine how water moves on the surface of Earth. Lesson 3 was designed to build on students' knowledge of how and why water flowed in particular directions so as to develop the students' understandings about watershed boundaries, and the locations that separate water flow.

In this lesson (lesson 3), students looked at maps of watersheds on a regional and national level to determine what counts as a boundary for a watershed. In the intended activities for lesson 3, students were expected to use their knowledge of how water flows on the surface of Earth to theorize about why the boundaries of watersheds are located where they are. Students were provided with several different maps at different scales and with different levels of detail. One of the maps was of Michigan's lower peninsula, and another was of the entire contiguous United States. It was intended that the students' work with water flow in the lesson before helped them develop a working definition of a watershed that included the concept of a downhill flow of water on the earth's surface that results in the collection of water in water bodies. In this lesson, students would add that watersheds exist at various scales and can be nested within one another.

Table 21. Outline of Lesson 3 Activities and Dimensions

Activity Name	Activity Description	Potential Dimensions to Integrate
	Day 1	
Student Definitions of Watershed	Table groups write answers to the question, "What is a watershed?"	Water and Earth's Surface Processes (DCI) + Scientific Explanation (SP)
Predicting Water Flow Using Models of Elevation	Adding high-elevation symbols to the map to indicate the direction of water flow in those areas. Teacher models how he would use a topographic map to determine which direction a river was flowing.	Water and Earth's Surface Processes (DCI) + Models (SP)
Class Definition of Watershed	Teacher uses the group definitions of a watershed to build a class definition.	Water and Earth's Surface Processes (DCI) + Scientific Explanation (SP)
What Determines A Watershed Boundary?	Students use maps of various scales to figure out what determines a watershed boundary. They use this definition to answer two questions.	Water and Earth's Surface Processes (DCI) + System Boundaries (CCC) + Models (SP)
Introduction to Homework Model and Explanation	Teacher provides students with specific information about doing the homework.	Water and Earth's Surface Processes (DCI) + System Boundaries (CCC) + Models (SP)
	Day 2	
Discussion About Large and Small Examples of Watersheds	As a class, the group discusses their answers to the questions from the worksheet the day before, "What is the largest watershed you can imagine?" and "what is the smallest watershed you can imagine?"	Water and Earth's Surface Processes (DCI) + System Boundaries (CCC) + Explanation/Argumentation (SP)

In the enactment of the lesson, the teacher added several sections of activity and instruction to the beginning of the lesson. Many of these activities further developed students' experience with watersheds. In the beginning of the lesson, students developed table-group definitions of "watershed" and then worked with maps to identify how water flowed in the landscape represented in the topographic map. Using the boundaries for water flow that appeared on the map (i.e., the high elevation points), the teacher had students think about how those points influenced water flow. Ultimately, the teacher developed a class definition using the student groups' definitions as a basis. The teacher added one key element that was not in the groups' definitions to the class definition—that a watershed is an area of land. At the end of the lesson, the teacher gave students instructions on how to approach the model that was their homework that night. In the next lesson (lesson 4), students were introduced to the concepts of porosity and permeability through looking at the flow of water through various Earth materials.

The following sections describe the activities listed in Table 21 more thoroughly, with a focus on describing the integrative aspects of the classroom activities and conversation. The sections are titled with the Activity Name that appears in Table 21, and they unfold in the same order they did in the class when lesson 3 was enacted.

Student Definitions of "Watershed"

At the beginning of lesson 3, students worked in their table groups to develop a definition of a watershed. The activity was introduced with dialogue from the teacher (Table 22). In this introduction (Table 22), the teacher framed the task in terms of a scientific explanation, asking the students to "think about all of the experiences we've had so far with all the activities we've done." Students were encouraged to think of activities that supported their idea of what a watershed is and to put it in their own words. The teacher also made clear the kinds of information that were acceptable to use as evidence by describing how other classes have used "their own experiences" and "the internet." This process of developing a small group definition is contrasted with what will follow, the development of a full-class definition, as introduced with the phrase, "We'll define it." Although the activity was set up for students to support their definitions with evidence from activities, students did not hold one another accountable to that, and ultimately the teacher did not either.

Table 22. Teacher Describes Activity Where Students Define the Term Watershed

Speaker	Dialogue	Features of the Dialogue
Teacher	We've been dancing around this word for a while now. Today finally we will address that answer of what a watershed is, we'll define it, but first I want to get your ideas of what is a watershed. Amazingly enough, your fellow compatriots in other class hours have miraculously come up with a definition, sometimes out of their own experiences, sometimes out of this thing called the internet. So I do want you guys to think about it, talk about it, think about all the experiences we've had so far with all the activities we've done. What defines what a watershed is? How would you put it into your own words? What are important things that are part of it? Try to talk about that among your group to see whether or not you can come up with a definition. (Lesson 3, lines 4-14)	Developing claims about what a watershed is. Description of what counts as evidence. Examples of evidence. Description of quality: (1) Own words; (2) List of necessary elements for a watershed.

Two of the small group conversations, captured by video, recorded the experience of seven students. One small group quickly started discussion, taking a while to co-develop their understanding of the concept (Table 23). They began discussing their understandings immediately after the directions were given, five minutes into class, and continued to discuss for five solid minutes. They only briefly paused to discuss where one of the students had been during the last class period. They settled on a definition during the following conversation captured on the full group video of the class.

Table 23. Dialogue Where a Small Group Builds a Definition of Watershed – Even Participation

Speaker	Dialogue	Keywords About Watersheds	Dimensions
312	My dad said like an area that like kinda directs the water to a river or something… an area that directs	An area Directs water To a river	DCI – Water Bodies
308	So maybe like a mountain or something directs...	A Mountain – High Elevation	DCI – Elevation
312	something that separates two bodies of water and	Separates Water Bodies	CCC – Boundary
308	tells the water where to go	Directs Water	
312	and directs where the water should go. There's a high point. So like... so basically the high point decides where everything goes so you know obviously so if the rain fell like on a smaller scale because you know if it rains on this side then it's [unintelligible] but anyways...	Directs Water	DCI – Elevation
308	If it rains everywhere.	Water Lands Everywhere	
312	If it rains on top right on the right side like really close like right here, then it would still go down the right side, but I said if it land like right on the high point then it would be at the high point and I was saying that it would kind of split that drop in two or whatever because then it would like you know.	Separates Water Flow	DCI – Water Movement DCI – Elevation CCC – Boundary
308	Is it..it drops on the high point it separates. Because gravity like pulls it both ways. (Lesson 3, lines 28-47)	Separates Water Flow Gravity Pulls Water	CCC – Boundary DCI – Elevation

After the two prominent players in the conversation decided on a group definition, they double-checked with the third person at their table, student 309, who may have been listening but perhaps not fully registering the conversation as it unfolded. The final definition that the group wrote on the board was, "Something that separates two bodies of water that has a high point that 'tells' the water to go." The double-checking process included reading the full definition to 309, and confirming that he agreed with what was said.

The other small group took a different approach (Table 24). Student 316 started by contributing a definition he had obtained from Google. The conversation was captured on the small group video, focused on these particular students, who also participated in the individual student interviews.

Table 24. Dialogue Where a Small Group Builds a Definition of Watershed – Uneven Participation

Speaker	Dialogue	Keywords about Watersheds	Dimensions
316	So water contained in a natural surface sort of?	Natural	
307	Uh I don't think that's exactly what it is.		
316	That's what Google told me.		
301	It's a water contained [unintelligible]	Water Contained	DCI – Water Flow
316	It's like water that doesn't flow. It doesn't flow anywhere.	Water Not Moving	DCI – Water Flow
307	that's not even right.		
301	No, it's like rain water that gets stuck in cracks.	Water Not Moving	DCI – Water Flow
307	Then ans...		
316	That's what Google told me.		
307	What it is is when water flows from higher elevation like mountains or something into a certain lower elevation, which creates a body of water.	Water Flow Downhill Body of Water	DCI – Water Flow DCI – Water Bodies DCI – Elevation
306	Okay		
316	So water flows	Water Flows	
307	like a river or a lake or something	Body of Water – Large	DCI – Water Bodies
301	Water that goes down the mountain flows down into the basin or a lake, stream, rivers, or forms a small little puddles.	Water Flows Body of Water – Large and Small	DCI – Elevation DCI – Water Bodies
307	No, not small puddles	Not Small Bodies of Water	DCI – Water Bodies
301	Well, not small puddles, but the lake sometimes.	Not Small Bodies of Water	DCI – Water Bodies
307	Body, just a body of water, it can be a lake or a river	Large Bodies of Water	DCI – Water Bodies
301	Lake or river or spring		
307	Should I go write it up? (Lesson 3 – Small Group, 10:03-11:26 minutes)		

In this example, student 307 seemed to arbitrate the contributions, acting as if she had the definitive understanding of the concept. Although students 301 and 316 actively tried to contribute to the conversation, 307 served as a kind of arbitrator of the truth. Student 301 tried to participate actively, but 301 and 307 had different understandings of the concept, which were not rectified in the conversation. Indeed, 307 had a more complete explanation, but the ideas that 301 and 316 contributed were discarded without much conversation. In both groups, members talked about looking up the definition online or using adults as resources.

This activity encouraged students to draw on their class experiences. Although some students were able to create very accurate descriptions of important elements of a watershed, none of them specifically described an in-class experience to support their response. Several students verbally cited outside sources such as parents and Google. Although some responses clearly showed that the students could verbally describe the concept, other students' descriptions revealed conflicting ideas. For example, one student described that water in a watershed "doesn't flow." Another student was uncertain of the role that puddles could play in watersheds. Ultimately, this activity served as a uni-dimensional activity, in which students contributed only knowledge related to the DCI.

In this activity, students, in their written responses, defined the DCIs without reference to the CCC or SP. Their conversations, on the other hand, were much more sophisticated **Error! Reference source not found.**(Table 23). Had students been drawing on more concrete pieces of evidence to support their definitions, this might have been an example of scientific explanation, another SP, but their lack of evidence made it more an exercise in making claims. Students 312 and 308 seemed to need more support to get all of their ideas represented in the small-group definitions written on the board, whereas the other group relied mainly on 307's understanding for their definition.

Predicting Water Flow Using Models of Elevation

In the next activity of lesson 3, students used the contour lines on topographic maps to identify areas of high elevation. The previous day, students had done an activity in which they identified the direction of water flow. The final question in that activity was, "How can you identify where the water in the river comes from?" It was intended that the students use the maps to find areas of high elevation that divided the flow of water. Students never seemed to get to that depth with the lesson 2 activity, so the teacher incorporated a more directive version into lesson 3. The activity began with a call-and-response review of what the map was called, what the symbols on the map represented, and what information could be found on the map. Once the students got to contour lines and reviewed what they represented, the teacher initiated the following conversation:

Table 25. Dialogue Where the Teacher Provides Verbal Support for Interpreting the Model

Speaker	Dialogue	Dimensions
Teacher	Contour lines. Remember those things? And if we note the general idea about contour lines, what tells us that it's really high or the elevation is really large at that area? How would we know through contour lines? Yes, [313]!	SP – Representing Elevation in a Model DCI – Elevation
313	Um like they get like closer together.	
Teacher	They get closer together means what?	
308	They get steeper.	
Teacher	They get steeper in elevation, right? We go another set amount of height in a certain amount of distance. What tells us that it's like a gradual kind of climb? How would we know that with contour lines? 308?	DCI – Elevation SP – Representing Slope in a Model
308	The lines are farther apart.	
Teacher	Farther apart so it’s gradually getting higher in elevation, right? Distance wise. As you travel along that line. So at this point, on your map, what I want you to do is have one person in the black color. Whoever has the black dry erase marker, I want you to indicate where there is high elevation. Where the elevation is really large in terms of height, and you're going to indicate that with a simple symbol like what? (Lesson 3.1, lines 185-204)	DCI – Elevation SP – Interpreting Areas of High Elevation in a Model

In this conversation, the discussion began with how to identify areas of high elevation. The approach the class used for finding higher areas was to look for steeper slopes. This sometimes works since when elevation increases quickly, the top is higher than the bottom of the slope. However, the connecting between steep slopes being near areas of high elevation is never made apparent for the students, and students may be led to believe that all areas of high elevation have a steep slope. The discussion concludes that they should be looking for steep and gradual slopes. At the teacher’s prompting, the students guessed a number of symbols that they might use to represent mountains—from circles to octagons to stars. During this process, the teacher did not provide any hints. He ultimately told the students what to use (Table 26).

The upside-down V used in this activity was the most commonly used elevation symbol in students’ models throughout the curricular unit. The conversation in Table 26, particularly in the last few lines, showed that the teacher’s nonspecific language led to some confusion. Student 307, in particular, saw that the entire map was covered with contour lines and thus wanted to cover the whole map with symbols, because the criterion for placing a symbol was that the area have contour lines. In this analytic process, students were intended only to identify areas of higher elevation. However, as can be seen from the conversation, this discussion was not linked to the previous activity, which defined watershed. Here, the connections were not made apparent to the students. In the next portion of the activity, students begin thinking about how water would move in relationship to the elevation represented on the map.

Table 26. Dialogue Where the Teacher Suggests a Notation for High Elevation and Describes Its Application

Speaker	Dialogue	Features of the Dialogue
Teacher	Upside down V! Because I want you to indicate with kind of like a mountain symbols. If you were on your map I want high elevation to be represented with these things here. So we're just kind of going to exaggerate the map a little bit. Where is the elevation high on this map? Find those areas on the map the person with the black marker. Other people, you can help them out if you want to point to them so they know where it is. Where is there high elevation?	An alternative representation for elevation – this same notation is consistently used in students' models
312	The highest?	
Teacher	Not the highest. I'm talking about high elevation. All around the map, where do you find it? Where do you find high points? If you need to use multiple mountain symbols, feel free to.	Science Practice – Identifying patterns in the data from a model
Teacher	I.e., like this, I just made my symbol for an area that has high elevation.	
311	Is it okay to be small?	
Teacher	Ummm, well, it's okay to be small but it has to be all around where you see elevation.	
311	Any elevation?	
Teacher	Any elevation.	
311	Okay.	
Teacher	Where do you see contour lines?	
307	Can we just scribble out the whole map? (Lesson 3.1, lines 215-236)	

Building on the students' identification of areas of high elevation, the teacher briefly reminded them about the mechanism of water flow before he had them add the direction of flow to their maps. In this dialogue, the teacher reminded the students what they had learned in previous lessons. There were few student comments or responses. The teacher directed students to the information they needed, and guided them to the activity, but there was very little checking that the students knew what to do.

Table 27. Dialogue Where the Teacher Verbally Supports Students to Make Connections Between the DCI and SP

Speaker	Dialogue	Dimensions
Teacher	Okay, next thing I want you to do on your map, and this is kind of a review of what happened last time. Let's see if you guys learned anything from last time cause it has been a week since we met last. Now that you know where elevation is, let's talk about the water cycle very briefly. If water happens to fall, because of the water cycle. Water's in the clouds, condensation starts to happen, rain falls down like last night. Did you guys hear the rain?	Teacher – DCI
Students	Yeah.	
Teacher	There's a lot of rain coming down. If rain were to fall on your map, right here. Using your ideas of elevation because what will happen with elevation and rain?	Teacher – DCI + SP
Student	It will go down.	Student – DCI
Teacher	It will hit something, and based upon whether how high or how low it might be in terms of elevation it might flow a certain direction right? And that was part of your homework. To figure out how do you explain where water flows if it happens to hit a certain landscape. What I want you to do with your other color. Not the black marker, but your other color now. Is to draw arrows where water would flow based upon elevation. Where would you see water flowing? Where would it go? Which direction? So, on your map, figure out which way water would flow. (Lesson 3: lines 251-271)	Teacher – DCI + SP Teacher – DCI + SP Teacher – DCI + SP

In walking around the classroom, the teacher saw that students were having difficulty identifying the direction of the flow of water. Most students may have been using the bodies of water alone to identify the direction of flow. As a result, the teacher introduced the following example into a conversation about determining the flow of water (Table 28). Using a line drawing of a river, a lake, and a creek, with the river and the creek on opposite sides of the lake, the teacher asked the students which direction the water would flow. Although the teacher unintentionally gave the students a strong hint about the correct answer, the students nearly unanimously agreed that it was very likely that the lake would flow into the creek.

Table 28. Dialogue Where the Teacher Develops Example Watershed for Analysis

Speaker	Dialogue	Features of the Dialogue
Teacher	But tell me this, if water goes down, first of all let's say there is a creek. We're going to call this [303] Creek. [303] Creek goes into, or is connected to I should say, we're going to call this	Development of a hypothetical example. Teacher – DCI + SP <Slip up. The teacher says the water flows from the creek to the lake, but students do not capitalize on this.>
Students	[305] Lake...	
Teacher	and connected to [308] Lake is…	
Students	[316] River.	
Teacher	Okay now explain to me if you will, since you people are smart scientists.	
Students	Hee-hee. Well I don't know about that.	
Teacher	Can [316] River go into [308] Lake?	
Students	Yeah.	
Teacher	Can [308] Lake go into [303] Creek?	
Students	Yeah.	Here the students still say that the large lake fed by a large river can drain into a small creek.
Student	Wellllll… Yeah.	

Note. The class dialogue during which the teacher sets up the example that the class will analyze, so as to understand how to determine the direction of water flow. (Lesson 3.1, lines 357-369)

The creek under discussion, [303] Creek, flowed into [308] Lake at one end and ended abruptly at the other end. When asked to explain where the water was going, the students said that it either was absorbed by the land or evaporated into the air. Through some probing, using additional questions, the teacher discovered that the source of confusion was the students' understanding of the rate of evaporation. In the dialogue in Table 29, the teacher asked the students to quantify, approximately, how long it would take for a glass of water to evaporate. In this way, the teacher was able to gain a sense of the students' understanding of the rate of evaporation and could compare the students' thoughts on the rate of evaporation to the hypothetical volume of water that would be leaving [303] Creek.

Once the students were convinced that evaporation and absorption could not explain what would happen to the water leaving [303] Creek, they were willing to accept that the water might be flowing in the other direction. The teacher then used their willingness to accept an alternative solution to help develop ideas from their definition of watershed—one of the main components of which was water moving to larger bodies of water.

Table 29. Dialogue Where the Teacher Reveals an Alternative Idea About Evaporation

Speaker	Dialogue	Features of the Dialogue
302	It's not disappearing, it's going over there [into the land], and it's going up there [into the air].	Student is still convinced of evaporation and absorption idea.
Teacher	It's going there and up there?	
302	Yeah. Yeah.	
Teacher	You have a glass of water, and you put it out in front of me. How long do you think it's going to take to evaporate that whole glass of water?	Contradictory Example.
312	A long time.	
302	10 minutes.	
307	10 days.	
Teacher	10 minutes? You have a weird sense of time.	
311	I did an experiment with that once. It goes like really slowly.	
Teacher	It goes like micro-millimeters worth of evaporation per day.	
302	Oh.	
311	It's like a millimeter.	
Teacher	10 minutes? It does not evaporate in 10 minutes. (Lesson 3.1, lines 436-451)	

Table 30. Dialogue Where the Teacher Demonstrates That Water Generally Moves to Larger Bodies of Water

Speaker	Dialogue	Dimensions
Teacher	So if we think about what we just talked about before, water flows which way?	Teacher – DCI + CCC
Student	Downhill	
Student	Down.	
Teacher	Downhill, right? If [303] Creek doesn't have this accumulation of tens of thousands of gallons of water, maybe like [308] Lake does. That seems like a natural area where water is going to collect there. It can hold it. So [316] River can flow into [308] Lake. That's possible. That makes sense. Can [308] Lake flow into [303] Creek?	Teacher – DCI + CCC
5 Students	No.	
Teacher	No, yet a lot of you told us. Not just this class but a lot of middle school classes they told me for example like this river the Rapid River, the major Rapid River, where it starts over here with some creeks down here that water flows this way. (Lesson 3.1, lines 462-475)	Relating hypothetical example back to the landscape on the maps.

Although the students were generally willing to accept this, it was confusing for them at times. For example, when they later looked at the continental watershed map, they realized that the Great Lakes, huge bodies of water, flowed into the St. Lawrence River, which seemed inappropriately small.

In the next part of the class, the teacher used what the students had learned about water moving to larger bodies of water in the class definition of a watershed. He drew a map on the board, a model (SP) to reveal students' understandings about the flow of water (DCI). In explaining their understandings, students used the mechanisms of evaporation and absorption as reasons they believed the water would flow in a particular direction.

Class Definition of Watershed

In the student definitions of watershed, 308 and 312 had a fairly sophisticated conversation about watersheds (see Table 23, p. 83). Both girls were contributing new information to the conversation that resulted in their group definition. Ultimately, they read the definition to the third member of their group to check what they had written. Their definition appeared on the board as "Something that separates two bodies of water that has a high point that 'tells' the water to go." Unfortunately, what they wrote on the board lost a lot of the nuances of the conversation. For example, their conversation started with the fact that a watershed was "an area," and ended with the contribution that all of the movement was because of the role of "gravity" in the interaction.

In contrast, in the other group, 307 appeared to have the final say about the definition of watershed (see Table 24, p. 84). Although the two boys in the group, 301 and 316, contributed some information, it was 307 who determined its accuracy. The student who instigated the discussion, 306, did not voice her opinion during the process. In the end, it was 307 who wrote the definition on the board: "Where water that falls on an area falling on that is high elevation, flows into an area of lower elevation, creating a body of water." In the example from the other small group, there was a conversation about the definition, but it seemed to include only 307's ideas (see Table 24, p. 84). Nothing from the conversation seemed to be included in the written definition.

While reading the groups' definitions, the teacher paused to identify key words that would play a part in the group definition, which developed slowly. Ultimately, he said, "Areas of land where water flows into larger bodies of water," and then he added, "but how do we know which way it goes?" Before finishing the definition, the teacher modeled how to determine the direction of flow using a topographic map taped to the board at the front of the room. Placing drops of water in strategic locations of the map, the teacher illustrated areas in which water could fall but be reunited downhill in a body of water. The "epic story" of water drops A through F showed the direction of water flow throughout the topographic map (see the map annotations in Figure 6). Through this process, the teacher highlighted areas of high elevation that divided water drops and water flow (Table 32).

Thus the teacher used the water droplets to highlight areas of high elevation, creating watershed boundaries (CCC). It is unclear what students were able to see during the modeling activity, which was used to support the final addition to the class definition, “divided by elevation.” Ultimately, the teacher developed the final class definition of watershed: “Area of land where water flows into larger bodies of water divided by elevation.” Although all of these parts make sense, and are crucial to understanding the role of a watershed, this definition flows more like a set of key words than a detailed explanation. This may have been a missed opportunity to use activities that relate to particular aspects of the definition as evidentiary support, thus making the definition more like a class scientific explanation.

In this process, at least one group (see Table 23, p. 83), though not prompted to do so, included a discussion of the division of water, representing a boundary to the system (CCC) in their discussion of the movement of water (DCI), although it was not included in their written definition. System boundaries were not included in the final group definition, either. Although the system boundary is not included formally, it was a large part of the conversation that led to the inclusion of “divided by elevation.”

Only the teacher used the practice of modeling in this activity. He used both the teaching practice of modeling how to do something and the science practice of analyzing data represented in a model, a topographic map. It was only the teachers’ presentation, modeling the practice of determining the slope of the land and direction of the flow of water to determine the boundaries, that brought together modeling (SP) with system boundaries (CCC) for the flow of water (DCI) in a watershed. Neither of the recorded groups supported their definitions with evidence from the activities in either their written definitions or conversations.

Table 31. Integrated Conversation About the Movement of Water Relative to Points of Higher Elevation

Speaker	Dialogue	Features of Dialogue	Dimensions
Teacher	So that's a dividing line. What about up here? This is a dividing line too. Let's say water droplet C.		
302	Noooo.		
312	Oooh rain.		
Teacher	We're gonna go that way, right? Right here is another dividing line, where there is high elevation.	Dividing lines are areas of high elevation. – DCI + SP + CCC	DCI – Elevation SP – Analyzing Models CCC – System Boundary
Student	That's water?		
Teacher	So letter D and letter E		
Student	Ooooh.		
Teacher	But guess what? Letter E will go into and letter D will go into... Oh wait they will meet each other!	Sometimes water drops in two different parts of a map are sent to the same place.	DCI – Water Flow SP – Analyzing Models Implied: CCC – Nested Systems
302	Yayyy!		
Teacher	Then letter F goes into where? Lake. Goes in that way, and ends up that way. So there's another dividing line here. So here, what I've done now is I've created kind of like in my mind, but also these water drops are going to follow, certain boundaries right? Where water can flow to, or not. A and B, they're probably not going to see each other for a while, because they is a division, there is a boundary that is set by what? (Lesson 3.1, lines 664-683)	Using "dividing lines" to create boundaries that divide where water goes. – DCI + SP + CCC	DCI – Water Flow SP – Analyzing Models CCC – System Boundary

What Determines a Watershed Boundary?

In this activity, students had access to three different types of watershed maps. Each map was developed to represent watershed boundaries (CCC). Students had a map of the major U.S. watersheds, a map of the watersheds and hydrologic features of the state, and a map of the local river watershed. Each map represented the watershed boundaries differently, and none of the maps made it clear why the boundary was located where it was. Each student had three questions to answer in their online interface (see Table 33). The first question appears to be a factual question, but it is open to interpretation in regard to what a watershed is. Implied in the phrasing of the question is that watersheds are nested (CCC), which students needed to accurately interpret before they could answer the question appropriately. For the second and third questions, the answer was open to argument. Students could answer the questions using information from the maps, or they could think about how the watersheds being represented might be a combination of several watersheds (i.e., could represent several nested watersheds), or could be combined to make a larger watershed.

Table 32. Questions From the Lesson 3 Handout

Question From the Lesson 3 Handout	Dimensions Integrated in the Question
How many watersheds are associated with the Huron River?	SP (Modeling) + DCI (Water's Movement on the Earth's Suface) Implicit: CCC (Nested Systems)
You do not have to locate it, but using your understanding of watersheds, what do you imagine is: • The largest watershed you can find? • The smallest watershed?	SP (Modeling) + DCI (Water's Movement on the Earth's Surface) Implicit: CCC (System Boundaries)
Missed Opportunity – Why do you think the watershed boundaries are located where they are represented?	Missed Opportunity – SP (Modeling) + DCI (Water's Movement on the Earth's Surface) + CCC (System Boundaries)

One opportunity was missed: Students could have been asked to explain why they believed the watershed boundaries existed where they did. Although students were using this information to answer other questions, this would have been an excellent opportunity for them to integrate their knowledge of why (CCC) the water (DCI) moves where it does in a watershed using models (SP) of watersheds.

Introduction to the Homework Model and Explanation

At the end of the lesson, the teacher provided the class with information about completing that night's homework assignment. Students had been failing to complete both parts of the homework assignment, probably because they were in two different places. Students had previously been asked to submit the model drawing on a sheet of paper, and the scientific explanation through an internet site called Moodle. From this night forward, the procedures were altered slightly in the expectation that it would support more students in completing the assignments. Both the model drawing and the scientific explanation would be completed on the same sheet of paper. This also allowed students access to scaffolds that were built into the worksheet version of the scientific explanation, which were impossible to replicate on Moodle. The teacher explained these new procedures to the students, and then he explained the homework assignment, due the next day, Friday. The directions unfolded in four parts, broken up as such in Table 33. First, the teacher read the model prompt, after which he reinterpreted the DCI information that the prompt was looking for.

Table 33. Directions for Completing the Homework Model and Explanation Following Lesson 3

Speaker	Dialogue	Dimensions	Type of Integration
Teacher	It says "draw a model of a watershed, be sure to include what influences how big the watershed is and what influences where the water goes."	DCI – Water Flow SP – Models CCC – Systems	Curriculum Prompt
	So on your drawing, I want to see what your representation of a watershed is. How large is your watershed? How are you determining how large that watershed is? So draw us a picture of an example, and it should be labeled. Labeled enough so that we know how large your watershed actually is, okay? And obviously what influences where the water goes.	DCI – Water Flow SP – Models [Implicit – CCC – System Boundary] SP – Models DCI – Water Flow	Integrative Directions
	On the back side, it's going to ask you the question, "how big can a watershed be?" That's a scientific question that we're asking you and we need a scientific answer. What's your claim? How big a watershed can be. Try to answer that there. Evidence, what gives you the idea, what gives you the facts, the data, of how large a watershed can be? How big it can be? And then your reasonings behind it, like why are you thinking that? What are your thoughts behind that? Okay? So that should be filled out on the back side, it's written. Drawing, written. (Lesson 3.1, lines 924-943)	DCI – Water Flow SP – Scientific Explanation	

In this expansion of the prompt, the teacher further expanded on the implicit inclusion of the CCC, keeping it an implicit element. He then explained the criteria for the model drawing: “draw a picture of an example,” “labeled enough so that we know how large your watershed actually is,” and “what influences where the water goes.” Finally, the teacher explained the scientific explanation. Here, he used a combination of directions about writing a scientific explanation, including the kinds of information that needed to be included in each section, and subtle reminders about how it should be done in the context of the DCI.

Only the model prompt and discussion included implicit reference to the CCC. The discussion about the scientific explanation includes the questions, “How big can a watershed be?” and “How large can a watershed be?” However, it is the discussion about the model that includes the more direct, but still implicit, reference to the CCC: “How are you determining how large that watershed is?” It is in the models produced for this homework assignment that the greatest number of students referred to the CCC.

Summary of Opportunities to Integrate From the Enacted Curricular Unit

In lesson 3, we see several instances in which the teacher incorporated an activity or modified an activity to make it more accessible to students, or to support students' making connections. The activity titled "Predicting Water Flow Using Models of Elevation" is a strong example of this. The activity itself was a variation on an activity from lesson 2. The teacher and researcher identified that students were not reaching the intended depth of understanding from the activity, so the teacher incorporated the activity into the lesson the next day, providing more detailed directions about how to identify the direction of the water flow. Even with the more detailed directions (Table 27, p. 88), students were still struggling with the activity. Seeing that students were having difficulty identifying the direction of water flow, the teacher added an example water system (Table 28, p. 89), and he created an opportunity for discussion, which revealed and attempted to dispel students' inaccurate assumptions about the flow of water (Table 29, p. 90, and Table 30, p. 90).

In reviewing the class activities that occurred during lesson 3, day 1, it is possible to break down what the expected opportunities to integrate were in each of the activities, and the opportunities to integrate (Table 34). The number of anticipated opportunities to integrate three dimensions was greater than the actual number of tri-dimensional opportunities to integrate. For most of the activities, it was anticipated that the CCC of systems would have a greater role than it actually did in the activity. There were in fact very few opportunities for the students to integrate the CCC in this lesson. The teacher spent a fair amount of time providing students with an example of analyzing a map (SP) demonstrating both the flow of water (DCI) and the boundary of the watershed (CCC), and developing a class definition of watershed that was integrative of the DCI and the CCC. The students seemed to have fewer explicit opportunities to do the integration themselves. This was in part because the activity questions were designed to implicitly integrate the CCC.

In these activities, there were several times when the teacher created examples to support students to overcome apparent misconceptions. In the first, the teacher created a series of water bodies and asked students to predict where the water would flow. Most students initially believed that the water from a lake would flow into a swamp and evaporate. This discussion brought to light students' misconceptions about evaporation and water flow. In the second example, the teacher drew drops of water on a topographic map and asked students to predict where the water would flow. This modeled for students the kind of analysis they could do using maps with elevation information. However, it was also a missed opportunity, because the teacher did most of the analysis through a modeled example, which was probably difficult for the students to follow in their own groups. Other missed opportunities for students to do the integrating sometimes occurred because the CCC was implicitly included in the curriculum prompts.

Summary of Students' Opportunities to Learn an Integrated Understanding

In the enacted curricular unit, students had many opportunities to integrate two of the three dimensions. Much class time was spent on activities in which students used an SP to better understand the DCI. Table 34 reveals the potential for integrating the CCC into conversations, but the curricular unit was not designed to explicitly integrate the CCC throughout the unit (Figure 3).

Table 34. Summary of the Activities From Lesson 3 and the Number of Dimensions Students Had an Opportunity to Integrate

Name of the Activity	**Development**	**Potential Dimensions of Science Education**	**Evaluation of Opportunities to Integrate**
Student Definitions of Watershed	Teacher	Water and Earth's Surface Processes (DCI) + Systems (CCC)	Student Opportunity – DCI
Predicting Water Flow Using Models of Elevation	Teacher & Curricular Unit – Repeat of lesson 2 activity, adding detailed directions for students	Water and Earth's Surface Processes (DCI) + System Boundary & Nested Systems (CCC) + Modeling (SP)	Teacher Discussion – DCI + SP Student Opportunity – DCI + SP
Example Determining Water Flow	Teacher	Water and Earth's Surface Processes (DCI) + System Boundary (CCC) + Modeling (SP)	Teacher Discussion – DCI + SP Student Opportunity – DCI + SP
Class Definition of Watershed	Teacher	Water and Earth's Surface Processes (DCI) + System Boundary (CCC)	Teacher Discussion – DCI + CCC Teacher Example – DCI + SP + CCC
What Determines A Watershed Boundary?	Curricular Unit	Water and Earth's Surface Processes (DCI) + System Boundary (CCC) + Modeling (SP)	Student Opportunity – DCI + SP
Introduction to Homework Model and Explanation	Teacher	Water and Earth's Surface Processes (DCI) + System Boundary (CCC) + Modeling (SP)	Teacher Discussion – DCI + SP Student Opportunity – DCI + SP + CCC

The CCC seemed to be used to clarify points of confusion. This was apparent in lesson 3, when the class discussed watershed boundaries using the flow of the drops of water. We also saw this in 311's move to clarify particular aspects of the DCI focused on aspects of the CCC. The integration of the CCC into the classroom discussion arose both from the teacher's modeling of the activities and from students' clarifications of confusing points. Integrative statements took several forms, including reading activity prompts, integrative directions, questions, statements, and integrative dialogue.

Change in Students' Expression of an Integrated Understanding of the Concept During the Unit

Analysis of Students' Responses to the Pre- and Post-Tests

The student work consisted of a pre-test and a post-test, as well as of all the models and explanations that students completed during the unit. Because the models and explanations were completed as homework assignments, not every student submitted each assignment. The range of completion rates was wide and depended on the assignments. The analyses below present the work collected from the students in section 3. All of the students in section 3 completed both the pre- and the post-test.

Initial analysis of the pre/post test results showed that explanation 1 and model 1 were poorly aligned to the content of the curricular unit. For explanation 1, no students had an integrated response on the post-test. The prompt was, "Write a scientific explanation to answer the question, How does water affect the shape of the landscape?" In retrospect, it is not surprising that the students' responses focused on how water erodes the landscape, creating canyons and breaking down rock. This was discussed briefly in the context of the field trip in the middle of the unit, but it was not a main learning goal for the unit. Most students used the Grand Canyon as evidence for their response. Although frequently accurate, the students' responses did not relate to the anticipated outcomes for the unit.

Although the responses to explanation 1 were not aligned with the outcomes for the unit, students' responses to conceptual model 1 were generally aligned with some of the goals of the curricular unit. The prompt was, "Draw a conceptual model of how water cycles in the [school name] schoolyard. Label the parts of your model." The most content-focused pre-test models showed water evaporating and cycling through the atmosphere, one component of the standard, and others showed elaborate systems for obtaining water. In their post-test models, students generally showed the movement of water along the surface of the schoolyard, but they often did not show a mechanism for the movement of water, or for gravity, the sun's energy, or change in elevation. Without showing a mechanism, the students failed to show any of the principles used in class.

Change in Students' Understanding of the DCI From Pre- to Post-Test

Change in Students' Understanding of the DCI as Represented in Models From Pre- to Post-Test

The pre- and post-tests were the same but used at two different times. Seven of the 17 students represented knowledge related to the DCI on the pre-test, leaving 10 students who showed an absent understanding ("0"). The questions may have biased their knowledge toward representing less than they actually understood, because the questions referred to students' knowledge of "watersheds." If a student was unfamiliar with the term "watershed," the question may not have activated related knowledge that the student could share. Despite this potential limitation, many students (7 of 17) showed a weak understanding ("–") for knowledge related to the DCI on the pre-test. These students represented water flowing downhill. The difference between earning a weak understanding and a thorough understanding ("+") for this category was whether the student represented the high point that served as a division of the flow of water, where water that falls on different sides of the high point flows to different destinations. This particular piece of information is integral to understanding the boundary of the system of a watershed (CCC). Only two students in the class represented this more nuanced understanding of the role of elevation in their post-test models (Table 35), students 302 and 312. Student 302's representation is discussed further below, and represented in Figure 10.

Table 35. Students' Pre- and Post-Test Representation of the DCI Using the Science Practice of Conceptual Modeling

DCI: Models	+s	–s	0s
Pre-Test Models		306, 307, 309, 312, 314	301, 302, 303, 304, 305, 308, 310, 311, 313, 315, 316, 317
Post-Test Models	302, 312	301, 303, 304, 305, 307, 308, 310, 311, 313, 314, 317	306, 309, 315, 316

Note. Each number refers to a single student's ID number. In the pre- and post-test, two of the three models were included in the analysis, and the highest DCI quality code was used to represent the students' achievement on each test.

The models that students did show largely represented water inside a shed or building, indicating a focus on human water systems. Figure 7 shows student 302's pre-test model of a watershed. Although it is speculated that some students' prior knowledge of water systems might not have been engaged because of the wording of the prompt, this students' learning trajectory indicates some evidence that this was not the case for all students who began the unit by drawing human water systems. Student 302 went through one iteration of a non-normative representation of watersheds before making his models much more accurate. This representation earned a "0" for content related to the DCI.

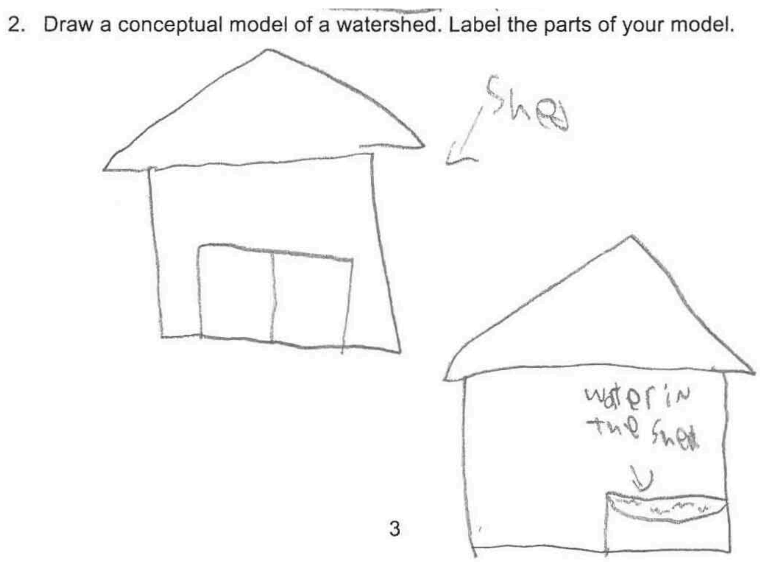


Figure 7. Pre-test model from student 302. The shed (labeled) contains a large barrel of water, labeled as "water in the shed."

Students who did show knowledge related to the DCI showed water moving from a high elevation to a lower elevation, as shown in Figure 8, where the student has labeled a point of high elevation, with rain falling from a cloud only on the area of high elevation. The water then travels downhill to what appears to be a man-made water tube, which takes the water to Lake Michigan. This image is a combination of manmade and natural features working together. This student, 312, earned a pre-test "–" for knowledge related to the DCI.

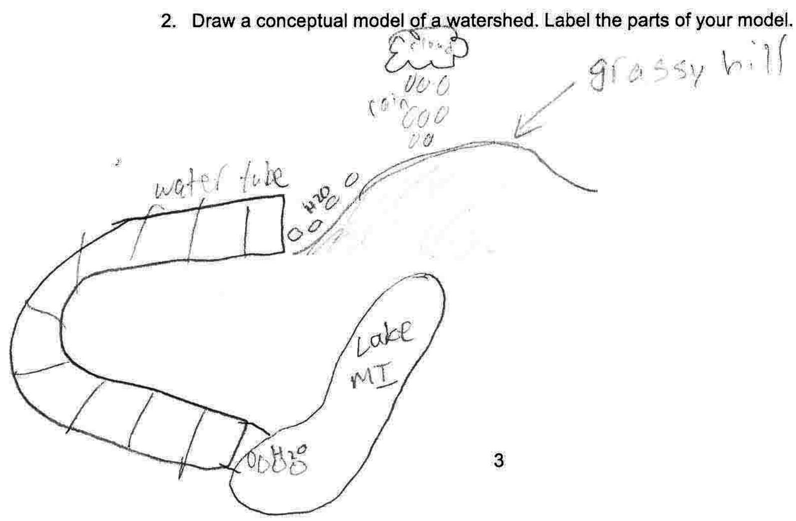


Figure 8. Student 312's pre-test model of a watershed. She showed water moving from a cloud onto the surface as rain; it then runs downhill into a tube that takes it to Lake Michigan.

The post-test models showed more understanding of content related to the DCI. Not always did students' models represent the information pertinent to understanding the concept, as shown in Figure 9. In this figure, the student has shown several key ideas from the unit: elevation, water bodies, and the connection between water bodies. What is missing is why the flow of water occurs. The areas of high elevation, labeled as mountains, surround the water bodies, with rivers flowing between them, and although arrows point from the mountains to the river, the relationship between the elevation and the water is unclear. What clarifies the relationship is the small illustration in the upper left corner, where the student shows a mountain illustrated with contour lines and water moving down the contour lines to areas of lower elevation. The larger illustration might get a "0" for not showing what influences the flow of water, but that small illustration earned the model a "–" for the DCI.

One clear representation of a changed understanding is seen when comparing student 302's pre-test model 2 (Figure 7) with his post-test model 2 (Figure 10). In the pre-test, student 302 drew a manmade system of a shed containing a barrel of water. In the post-test, he showed areas of high elevation and water traveling to and collecting in larger bodies of water. The student showed the areas of high elevation dividing the path of the water flow, sending water into two different water bodies, resulting in its being coded with a "+" for DCI. The points of high elevation are also labeled to serve as dividing lines, or boundaries, for the watershed, resulting in its being coded with a "+" for CCC.

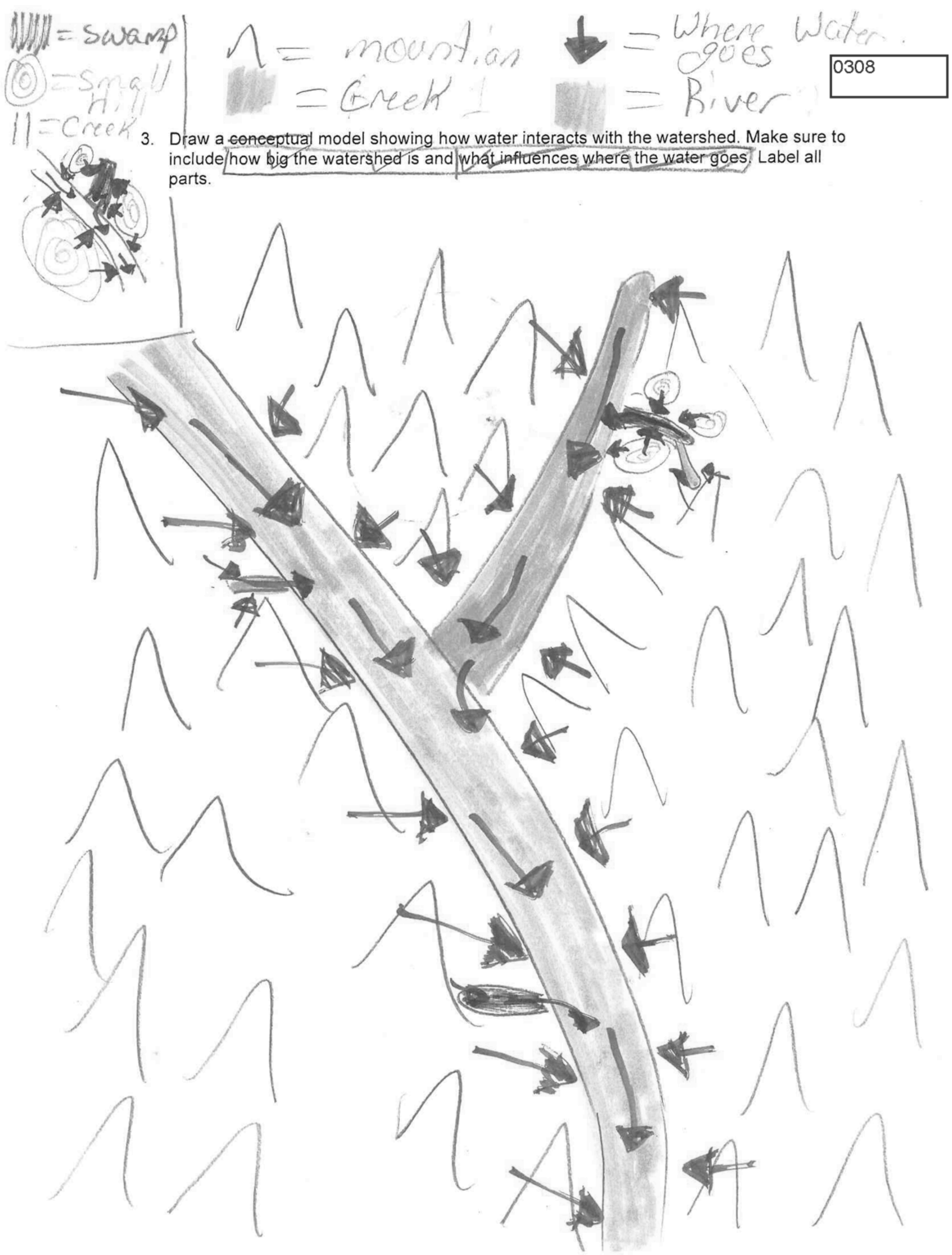


Figure 9. Post-test model from student 308. This model shows two water bodies connecting, and mountains surrounding the water bodies. The arrows show water moving from areas with high elevation into the rivers, but it is the small illustration in the upper left corner that makes the relationship between the water and the elevation clear.

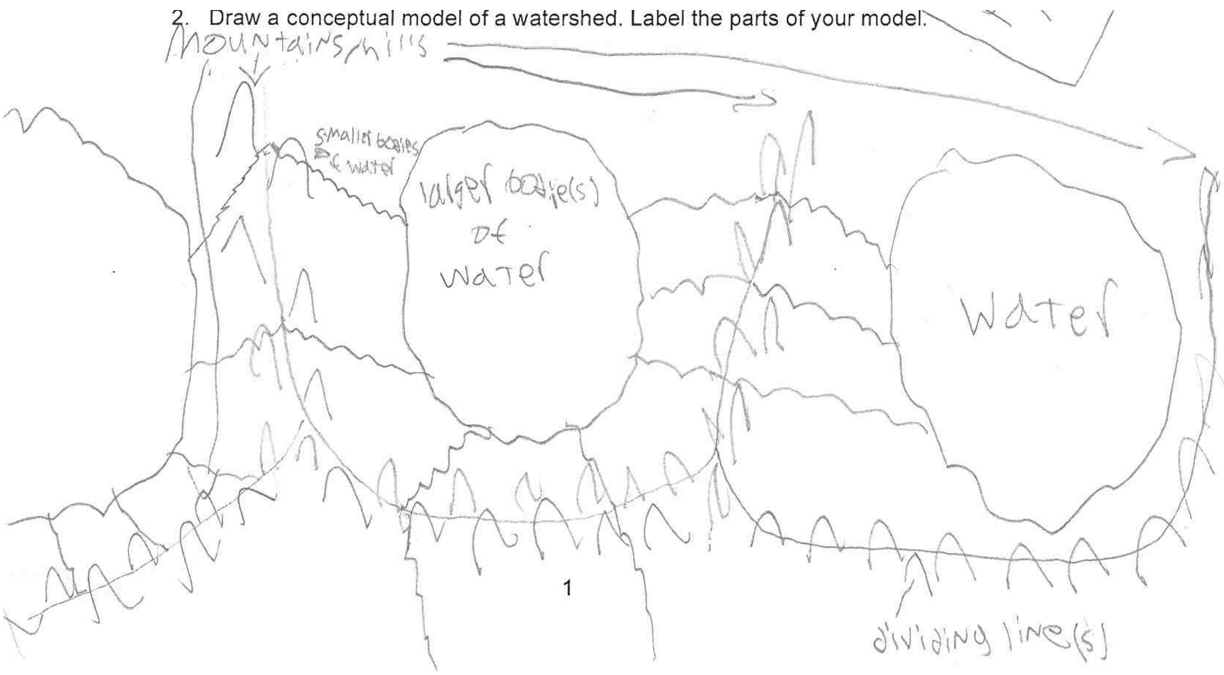


Figure 10. Post-test model of student 302. This model clearly represents areas of high elevation, labeled as “mountains/hills”, and areas of lower elevation, the larger bodies of water. It also shows the areas of elevation that divide the flow of water and send it to two different bodies of water, earning a DCI “+.” This model also shows a watershed boundary, which is labeled, earning it a CCC “+” as well.

In terms of growth of understanding as represented in the conceptual models, the overall change of each student is represented in Table 36. In this table, student 302’s models showed the greatest change in knowledge of the DCI. His models went from a lack of related content to a thorough understanding of the nuances of the DCI. The extent of change in understanding seen in student 302’s models is an extreme example and is not representative of the change typically seen in these students. Student 312 also had a thorough representation of the DCI in her post-test models, but she started from a greater understanding than 302, as her pre-test model included reference to water traveling downhill. Seven students went from no represented knowledge related to the DCI to a weak understanding, where a weak understanding meant showing water flowing downhill or infiltrating into the surface of the earth. Ten students showed either less content-related knowledge or equal amounts of pertinent information in their post-test and pre-test models. Student 311 was an example of a stable representation: she drew very similar models throughout the unit, without changing her representation much at all. Later in this chapter, her case is contrasted with that of 302 in considering what might have influenced such different trajectories.

Table 36. Students' Pre- and Post-Test Change in Representation of the DCI Using the Science Practice of Conceptual Modeling

DCI: Models	0 to +	– to +	0 to –	Both Models at –	Finished at 0
Students	302	312	301, 303, 304, 305, 308, 310, 311, 313, 317	307, 314	306, 309, 315, 316

Note. Each number refers to a single student's ID number. In the pre- and post-test, two of the three models were included in the analysis, and the highest DCI quality code is used to represent the students' achievements on each test.

The models of students 307 and 314 were marked as "stable," but their pre- and post-tests had different representations. In these cases, the differences were too fine grained for the coding rubric to pick up. For example, in the pre-test model (Figure 11), student 307 showed an area of high elevation and an area of low elevation with multiple rivers connecting the two areas. The model looks like two lakes with multiple rivers connecting the two lakes, which, as shown, is an unlikely natural occurrence. The post-test model (Figure 12) looks much more accurate, showing rivers flowing between areas of high elevation (mountains), and streams feeding the rivers moving downhill. The model has a watershed boundary, which would earn a higher CCC code "–." Why the boundary is located there was not specified, which means that although the post-test model represents a more sophisticated understandings, it represents similar knowledge of how elevation relates to the flow of water. One difference that the coding rubric was too coarse grained to pick up is that the pre-test model represents multiple parallel flows of water and the post-test represents connected water bodies feeding into larger bodies of water, a more accurate representation of the natural phenomena.

Other students did not seem to recognize which information was pertinent to explaining the phenomenon. For example, one model included mountains with a river in front of it, but no apparent relationship between the mountains and the river. Therefore, it was coded "0" for the post-test model. It is unclear whether these students did not understand the phenomenon or did not understand how to explain the phenomenon with a model.

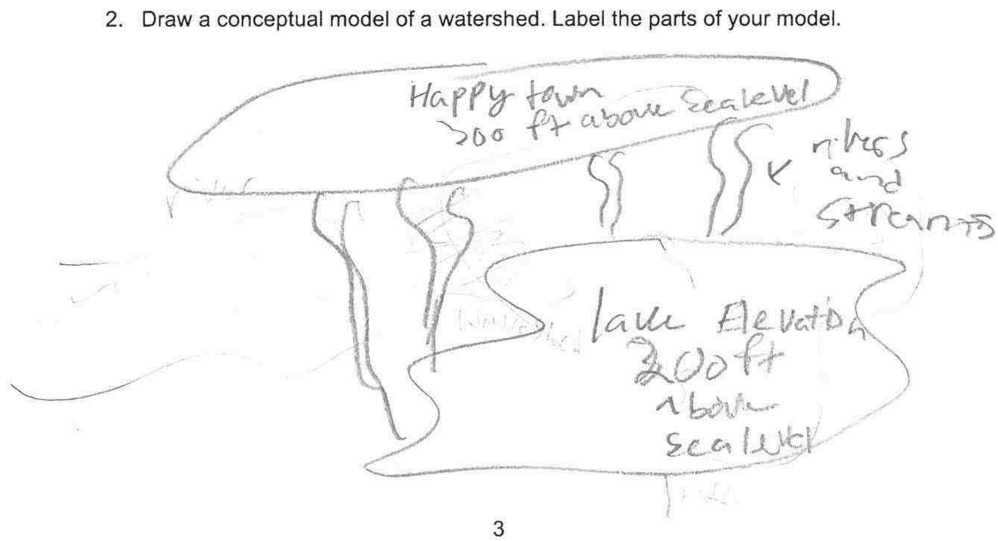


Figure 11. Pre-test model 2 created by student 307. This model appears to show two areas, one of high elevation and one of low elevation, connected by multiple streams and rivers. The model shows that elevation plays a role in water movement, but it does not show how or why that occurs, and the multiple connections between the two areas is very unlikely.

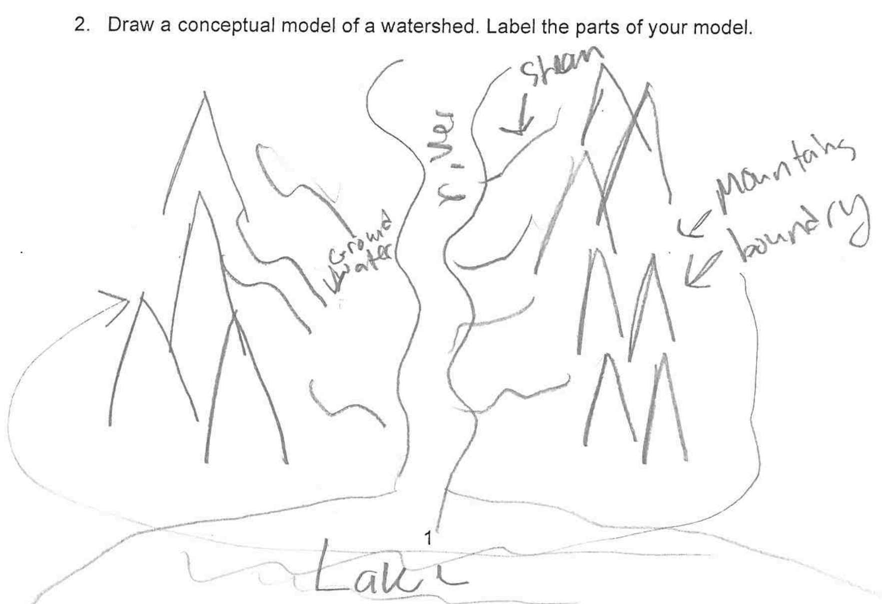


Figure 12. Post-test model 2 created by student 307. This model appears to show streams moving down to a river from the mountains, with some water labeled as moving to ground water, though how or why is not represented. The mountains are labeled as being the location of a boundary, but where the boundary is located and why is unclear.

Change in Students' Understanding of the DCI as Represented in Scientific Explanations From Pre- to Post-Test

Most students (11 of 17) did not improve their representation of content related to the DCI in scientific explanations. One student, 302, showed great improvement, moving from an absent understanding of the DCI in the pre-test to a thorough understanding in the post-test. Two students showed decline in represented content knowledge, moving from a weak to an absent understanding. One student started and ended with a weak understanding, and four other students moved from an absent to a weak understanding.

Table 37. Students' Pre- and Post-Test Change in Representation of the DCI Using the Science Practice of Scientific Explanation

DCI: Scientific Explanations	**+s**	**–s**	**0s**
Pre-Test		304, 306, 307	301, 302, 303, 305, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317
Post-Test	302	301, 303, 304, 305, 311	306, 307, 308, 309, 310, 312, 313, 314, 315, 316, 317

Note. Each number refers to a single student's ID number. In the pre- and post-test, one of the two scientific explanations was included in the analysis.

In his scientific explanations, student 302 provided evidence and reasoning in both the pre-test and the post-test responses. All three parts of the explanation are clearly aligned in both responses, making it easy to compare his understanding of the DCI. To obtain the pre-test "+" seen in Table 38, student 302 used reasoning ("watersheds are part of a water purification plant") to explain why he believed that the Mediterranean Sea had one. It is clear from what he wrote that he does not understand what the word "watershed" represents, but it is not clear whether he does not recognize the word well enough to represent related material or he does not know any related material. His work during the curricular unit reveals that it is the latter. (This analysis is described in The Case of Student 302, on page 131.)

Table 38. Student 302's Pre-Test Scientific Explanation Response

	Student 302's Pre-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	No, the Mediterranean sea does not have a watershed.
Evidence:	From what I understand about watersheds (which is basically nothing) watersheds are part of a water purification plant, and from what I understand about the geography of the Mediterranean Sea (which is also basically nothing) there are no water purification plants near the Mediterranean Sea.
Reasoning:	[Blank]

In student 302's post-test scientific explanation (Table 38), he used evidence based on his understanding of watersheds, as well as the definition of watersheds developed in class, to support his claim that the Mediterranean Sea has a watershed. His inclusion of the statement, "in fact, it has many watersheds," references the systems concept of nested systems, acknowledging that a watershed often includes many subordinate watersheds. His evidence includes reference to higher elevation separating parts of land, and then he connects these ideas to the class definition for a watershed.

Table 39. Student 302's Post-Test Scientific Explanation Response

	Student 302's Post-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes, the Mediterranean Sea has a watershed. In fact, it has many watersheds.
Evidence:	From what I understand, the Mediterranean Sea has land surrounding it, a vast expanse of land, and parts of that land are separated by higher elevation.
Reasoning:	A watershed is, "an area of land in which water flows into larger, more central bodie(s) of water, divided by elevation." I stated in my evidence that these areas exist around the Mediterranean, and they fit the definition of a watershed.

These two scientific explanations viewed together represent student 302's change in understanding of the science content as conveyed in a scientific explanation. Although the pre-test is based on a scientifically inaccurate response, the post-test explanation is an accurate response supported by thorough evidence and the class definition of a watershed. Not all students responded as clearly as student 302, which often made it difficult to judge the quality of a student's understanding related to the DCI. For example, the thinking was less visible in both of student 312's responses. In her pre-test response (Table 40), the connections between her claim, evidence, and reasoning are much less clear. She stated that the Mediterranean Sea does have a watershed, but her evidence is focused on the location of political boundaries, or perhaps the location of land. Her reasoning was based on the location of natural features, inaccurately, and drew the accurate conclusion that "it has to have a watershed otherwise there wouldn't be any water in it." This scientific explanation does not clearly represent student 312's thinking, limiting the reader's ability to interpret her understanding of the DCI. Her apparent lack of facility with the SP of scientific explanation apparently hindered her ability to explain her thinking.

Table 40. Student 312's Pre-Test Scientific Explanation Response

	Student 312's Pre-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes, it does have a watershed.
Evidence:	It's in the middle of a bunch of countries.
Reasoning:	Since it's not connected to any other sea or ocean, I think it has to have a watershed otherwise there wouldn't be any water in it.

Like her pre-test explanation, student 312's post-test scientific explanation (Table 41) is also unclear. The evidence focuses on the connections between bodies of water, without saying how the bodies of water are connected, or why that might be important for determining whether an area has a watershed. This explanation seems to be built on the assumption that if a body of water feeds into another body of water, the source is a watershed for the destination body of water. The reasoning that supports this line of thinking is that a body of water cannot get water only from rain. The way the reasoning is worded ("if it's part of a watershed then it should have it's own watershed") seems to imply the role of nested systems, but it does so only subtly.

A comparison of these two explanations shows that it is the student's lack of clarity that makes it difficult to see growth. In both representations, she might have an accurate understanding of the DCI, but the responses are missing the additional details that would support that understanding. Both of her responses earned a 0 for content related to the DCI, as neither response mentions the role of elevation in determining the flow of water in a watershed.

Table 41. Student 312's Post-Test Scientific Explanation Response

	Student 312's Post-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes, the Mediterranean sea has a watershed.
Evidence:	The Mediterranean Sea is connected to the Red Sea, which is Connected to the Arabian Gulf, which is connected to the Indian Ocean.
Reasoning:	The Mediterranean Sea can't get water only from rain, it has to have some other source. Also, if it's part of a watershed then it should have it's own watershed.

Only a small proportion of the students in section 3 showed any improvement in their scientific explanations over the course of the curricular unit (Table 42). For many of the students who scored an absent understanding on the post-test, the lack of improvement seemed to be associated with a response that was not thorough enough to represent understanding of the DCI, as seen in the difficulty that student 312 had with her explanations. Only three students had even a weak understanding of the DCI in the pre-test. One of these students maintained a weak understanding in the post-test, but the other two students finished with an absent understanding. Five students showed improvement, the greatest being in the DCI represented in student 302's scientific explanations.

Table 42. Students' Pre- and Post-Test Change in Representation of the DCI Using the Science Practice of Scientific Explanation

DCI: Scientific Explanations	**0 to +**	**– to +**	**0 to –**	**Both Explanations at –**	**Finished at 0**
Students	302		301, 303, 305, 311	304	306, 307, 308, 309, 310, 312, 313, 314, 315, 316, 317

Note. Each number refers to a single student's ID number. In the pre- and post-test, one of the two scientific explanations was included in the analysis.

Change in Students' Understanding of the DCI From Pre- to Post-Test

Most students (13 of 17 students) represented at least a weak understanding of the DCI on their post-test. Eleven of 17 students represented a better quality of understanding related to the DCI on the post-test than on the pre-test, and 4 of 17 students had a "0" quality representation of the DCI on the post-test in both their models and their explanations. More students were able to show an increased understanding using the models than the scientific explanations. In the post-test models, 13 students showed weak or thorough understandings of the DCI, whereas in the scientific explanations, only six students represented weak or thorough understandings of the DCI. Students seemed to have more difficulty representing what were considered integral components of the DCI in the explanations than they did in the models.

Change in Students' Understanding of the SP From Pre- to Post-Test

Change in Students' Understanding of the SP of Modeling From Pre- to Post-Test

For students to earn a score of weak or thorough for the models, they needed to show movement in their representations. The most thorough models showed the mechanism for the movement and included labels to help the reader understand the mechanism. Weak representations of the SP might have been insufficiently labeled and explained, or else they included more textual explanation than the illustration represents. Models that earned a "0" for the SP did not clearly represent movement. In terms of the scientific explanation, those that included a claim that answered the scientific question and evidence to support the claim were coded with a "–." Those that included reasoning, whether a scientific principle or a scientific idea to tie the claim to the evidence, were coded with a "+." The SP coding for the models and explanations did not account for the accuracy of the content, meaning that students who represented inaccurate information thoroughly in a way that conveyed their understanding received a high score for the SP, but they earned a lower score for the DCI or CCC (or both).

Students drew three conceptual models for the pre- and post-tests. Of those three models, two were used in the analysis (the third was determined to be too loosely related to the content—see discussion in the Methods chapter). For the coding of the conceptual models, the highest code for either model represents the student's achievement as represented in Table 43. Using the SP of modeling, many students (11 of 17) were able to develop a representation of their understanding during the pre-test. An even larger proportion of students (15 of 17) produced at least a weak representation of their understanding for the post-test. Although it is likely that most students had prior experience with drawing, few if any had prior experience with representing their understanding of a scientific phenomenon using a conceptual model. Only two students' post-test models showed an absent understanding for SP—students 309 and 315.

Table 43. Students' Pre- and Post-Test Representation of the SP of Conceptual Modeling

SP: Models	**+s**	**–s**	**0s**
Pre-Test Models		301, 302, 303, 304, 306, 307, 309, 310, 311, 312, 314	305, 308, 313, 315, 316, 317
Post-Test Models	301, 304, 305, 308, 310, 311	302, 303, 306, 307, 312, 313, 314, 316, 317	309, 315

Note. Each number refers to a single student's ID number. In the pre- and post-test, two of the three models were included in the analysis, and the highest DCI quality code is used to represent the students' achievements on each test.

Student 302’s post-test model is an example of a weak model in terms of its ability to explain the phenomenon. Its science content is mostly accurate, but it does a poor job of explaining how the process works (Figure 10, p. 103). The model does not explain why the water is flowing, or in which direction. It could have earned a “+” for the SP if additional information about the mechanism had been included. As an example of a “+” for the SP of modeling, student 308’s model (Figure 9, p. 102) includes a detailed key explaining the symbols she used, and she zoomed in on a section of the larger illustration. The expanded inset in the upper left corner explains the mechanism by showing a mountain with contour lines, representing water flowing downhill from the top of the mountain. This device increases the quality of the model by showing how and why the water moves on the surface of the earth.

Change in Students’ Understanding of the SP of Scientific Explanation From Pre- to Post-Test

One of the two scientific explanations in the pre- and post-test was used in the analysis (see the Methods chapter for a discussion of why the second explanation was excluded). For that explanation, most students (9 of 17) included both a claim that answers the scientific question and evidence to support the claim on the pre-test, earning at least a “–” on their explanation (Thirteen of the 17 students in this section of the middle school science classes were in 7th or 8th grade, meaning that many had been at the same school the previous academic year and had used a research-based curriculum that emphasized scientific explanations the previous spring. Of the nine students who had a weak or thorough understanding in the pre-test use of the SP of scientific explanation, one was in 6th grade so would have been unlikely to have experienced scientific explanation previously. Several (three of four) of the students who had a thorough understanding of the SP in the pre-test had a weak understanding in the post-test. This may indicate that as they learned more about the content, they struggled to determine what to include as reasoning to support their scientific explanation.

Table 44). Of those students who included evidence, five also included reasoning, earning a “+” on their pre-test use of the SP of scientific explanation.

Thirteen of the 17 students in this section of the middle school science classes were in 7th or 8th grade, meaning that many had been at the same school the previous academic year and had

used a research-based curriculum that emphasized scientific explanations the previous spring. Of the nine students who had a weak or thorough understanding in the pre-test use of the SP of scientific explanation, one was in 6th grade so would have been unlikely to have experienced scientific explanation previously. Several (three of four) of the students who had a thorough understanding of the SP in the pre-test had a weak understanding in the post-test. This may indicate that as they learned more about the content, they struggled to determine what to include as reasoning to support their scientific explanation.

Table 44. Students' Pre- and Post-Test Representation of the SP of Scientific Explanation

SP: Explanation	**+s**	**–s**	**0s**
Pre-Test	302, 306, 307, 311	304, 308, 310, 312, 314	301, 303, 305, 309, 313, 315, 316, 317
Post-Test	302, 303, 308, 310, 314, 317	301, 304, 305, 306, 307, 311, 312, 316	309, 313, 315

Note. Each number refers to a single student's ID number. In the pre- and post-test, one of the two scientific explanations was included in the analysis.

Two students went from an absent understanding for scientific explanation to a thorough understanding. One of these two students (317) had a blank pre-test explanation, which does not help us understand what his pre-test capacity for explanation was. In the post-test, student 317 wrote a brief but accurate scientific explanation, which included evidence and reasoning (Table 45). In his explanation, he accurately answered the scientific question with a claim. His evidence supported the claim, and the reasoning supported the claim. However, this student's evidence and reasoning do not support one another. Some additional information about what defines a watershed would have improved this student's reasoning, and additional information about the Mediterranean Sea would have improved his evidence.

Table 45. Student 317's Post-Test Scientific Explanation Response

	Student 317's Post-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes, the Med. Sea does have a watershed.
Evidence:	Water flows into it
Reasoning:	All bodies of water have watershed.

The other student whose explanation showed significant growth in understanding of the SP was student 303. In her pre-test response, student 303 used what seems to be logic rather than an observation or fact (Table 46). Rather than describing what she observed or was aware of, she described what must be true because of logic. For her reasoning, she did the same thing. Rather than explaining the phenomenon—what a watershed is—she asked for an alternative explanation.

Table 46. Student 303's Pre-Test Scientific Explanation Response

	Student 303's Pre-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Is a stream that flows into water.
Evidence:	The water has to come from somewhere
Reasoning:	Without a watershed how would the lakes/oceans have water.

Student 303's post-test scientific explanation (Table 47) has room for improvement as well, but it is a much more complete scientific explanation than her pre-test explanation. As seen in Table 47**Error! Reference source not found.**, the evidence statement is a complete sentence that does not entirely answer the scientific question but is counted as a claim. The evidence and reasoning are included together in the reasoning section. Here, the statements "every watershed has to flow into a larger body of water" and "also has to be divided by elevation" represent the scientific principles that explain a watershed. The other two sentences, "the Mediterranean flows into the Atlantic Ocean" and "there are higher points directing water into the Mediterranean Sea," are pieces of evidence directly related to the reasoning statements that connect back to the claim. In this explanation, the student's statement to answer the scientific question could have been clearer, and she could have separated the evidence and reasoning, using the explanation template more clearly, but the explanation is a definite improvement from the pre-test explanation, which did not answer the question at all.

Table 47. Student 303's Post-Test Scientific Explanation Response

	Student 303's Post-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes.
Evidence:	Yes, because it flows into a larger body of water that is divided by elevation.
Reasoning:	Every watershed has to flow into a larger body of water. The Mediterranean flows into the Atlantic Ocean. Also has to be divided by elevation. There are higher points directing the water into the Mediterranean Sea.

Change in Students' Use of the Science Practices From Pre- to Post-Test

Overall, 8 of the 17 students improved their use of the SP of scientific explanation (Table 48). Five of the 17 students improved their scientific explanations from an absent understanding to a weak or thorough understanding of the SP, and the remaining three students improved from a weak to a thorough understanding. An additional six students maintained a weak or thorough understanding of the practice. In total, 11 of 17 students improved or maintained their score for the practice of scientific explanation on the post-test. Three of the six students whose scores declined went from a thorough to a weak understanding, maintaining a non-absent understanding. The remaining three students finished with an absent understanding for their use of the SP of scientific explanation.

Eleven of 17 students represented movement in their pre-test models (Table 49), and 15 of 17 students represented movement in their post-test models. Six of 17 students had thorough ("+") post-test models and nine students had weak ("–") post-test models. In the post-test, six students had models that clearly showed a mechanism for the movement of water. For the SPs, 9 of 17 students showed growth in their use of the practice. However, six of the eight students who did not show growth were consistent in representing a weak use of the practice in both tests.

Table 48. Students' Pre- and Post-Test Change in Representation of the SP of Scientific Explanation

SP: Scientific Explanation	**0 to +**	**– to +**	**0 to –**	**Both Explanations at +/–**	**Decline OR Finished at 0**
Students	303, 317	308, 310, 314	301, 305, 316	302, 304, 312	306, 307, 309, 311, 313, 315

Note. Each number refers to a single student's ID number. In the pre-test and the post-test, one of the two scientific explanations was included in the analysis.

Table 49. Students' Pre- and Post-Test Change in Representation of the SP of Conceptual Modeling

SP: Models	**0 to +**	**– to +**	**0 to –**	**Both Models at –**	**Finished at 0**
Students	305, 308	301, 304, 310, 311	313, 316, 317	302, 303, 306, 307, 312, 314	309, 315

Note. Each number refers to a single student's ID number. In the pre-test and the post-test two of the three models were included in the analysis.

Change in Students' Understanding of the CCC From Pre- to Post-Test

In the coding of the CCC, the students' representations of the CCC were not independent of the DCI. Two components of the CCC were more easily and concretely identified in students' work (see the Methods chapter for a more complete explanation of this decision process); these were the elements of a system boundary and nested systems. For a student to show a thorough understanding of the CCC of a system boundary, he or she needed to show that elevation serves as a boundary for a watershed. A student who stated or showed only that the watershed had a boundary would earn a "–." To earn a thorough understanding ("+"), the student also had to show that elevation created the boundary. The requisites for a thorough representation of the CCC are related to those for a thorough representation of the DCI of elevation. To earn a thorough representation of the DCI of elevation, a student needed to show that elevation divides water, sending it in two directions.

Change in Students' Understandings of the CCC From Pre- to Post-Test

For a strong example of the CCC represented in a model, return to student 302's post-test conceptual model (Figure 9, p. 102). In this model, the student drew lines labeled as "dividing lines" above a row of mountains, showing that the mountains served as the watershed boundary. A more common representation of the CCC was the inclusion of an implied nesting of systems. In student 308's post-test model (**Error! Reference source not found.**, p. **Error! Bookmark not defined.**), she included multiple connecting rivers and streams. Although she did not specifically state it, this referenced the CCC of nested systems, where each river and stream has a watershed, which is part of the watershed of the larger river. The joining rivers and streams earned her a weak understanding ("–") for the CCC.

The one student who earned a weak understanding ("–") for the CCC on his pre-test scientific explanation, student 314, included a subtle reference to rivers having watersheds and being a part of the watershed of the Mediterranean Sea (Table 50). He said, "I think that if a river has a watershed, it can still be one. So a river is a watershed and I am almost positive that the Mediterranean Sea has a river flowing into it." Interestingly, his pre-test model did not clearly convey this same level of understanding relative to the CCC. His models showed water flowing downhill to enter a river. The stream of water joining a larger body of water could be interpreted as a nested system, but it did not qualify using the specifications for a nested system in this analysis.

Table 50. Student 314's Pre-Test Scientific Explanation Response

	Student 314's Pre-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	Yes.
Evidence:	Most if not all big bodies of water have a watershed.
Reasoning:	I think that if a river has a watershed, it can still be one. So a river is a watershed and I am almost

	positive that the Mediterranean Sea has a river flowing into it.

On the post-test, the scientific explanation of one student, 308, was coded as a thorough understanding of the CCC. In this explanation (Table 51), the student described both the things that flowed into the watershed and the destination of the watershed, showing the nested nature of the systems. This is seen in the reasoning for the explanation, where the student wrote, "There are things that flow into the sea, and some of the seas water flow out into an ocean." These components could also be interpreted as a discussion of the inputs and outputs of the system, a component of the CCC not coded for in this analysis.

Table 51. Student 308's Post-Test Scientific Explanation Response

	Student 308's Post-Test Response
Scientific Question:	**Does the Mediterranean Sea have a watershed?**
Claim:	The Mediterranean Sea has a watershed.
Evidence:	Rivers flow into the sea and the sea flows into a ocean.
Reasoning:	There are things that flow into the sea, and some of the seas water flows out into a ocean.

All students showed an absent understanding for their pre-test representation of the CCC in their conceptual models (Table 52), and only one student represented the CCC in the pre-test scientific explanation (Table 53). In the post-test models, two students (302 and 303) showed a thorough understanding of the CCC, nine students' models showed a weak understanding, and six students' models had no indication of the CCC.

Table 52. Students' Pre- and Post-Test Representation of the CCC Using the Science Practice of Conceptual Modeling

CCC: Models	**+s**	**–s**	**0s**
Pre-Test			301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317
Post-Test	302, 303	301, 304, 305, 307, 308, 311, 312, 314, 317	306, 309, 310, 313, 315, 316

Note. Each number refers to a single student's ID number. In the pre- and post-test, two of the three models were included in the analysis. Students' scores represent their highest achievement in the two models.

Both examples of students who referenced the CCC in their scientific explanations did so by including reference to the CCC in their reasoning, not in the claim or in the evidence. This makes sense because the CCC ties the specific example from the curriculum, watersheds, to a broader concept, systems, or gives students a way to define the watershed using a standard language for describing its components. Both of these visions of the CCC fall into the realm of the scientific explanation's reasoning, a scientific idea or principle that ties the evidence to the claim.

Table 53. Students' Pre- and Post-Test Representation of the CCC Using the Science Practice of Scientific Explanation

CCC: Explanation	+s	–s	0s
Pre-Test		314	301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 315, 316, 317
Post-Test	308	312	301, 302, 303, 304, 305, 306, 307, 309, 310, 311, 313, 314, 315, 316, 317

Note. Each number refers to a single student's ID number. In the pre- and post-test, one of the two scientific explanations was included in the analysis.

Change in Students' Understanding of the CCC From Pre- to Post-Test

Some students showed growth in understanding of the CCC associated with the curricular unit. Many students (11 of 17) at least subtly referenced the CCC in their post-test models (Table 54). Six students had an absent understanding on their post-test models. This proportion was much greater than the number of students (2 of 17) who referenced the CCC in their post-test scientific explanations (Table 55). This stark difference in the number of students who represented a reference to the CCC indicates that it may be more difficult to incorporate the CCC into an explanation than into a model.

Table 54. Students' Pre- and Post-Test Change in Representation of the CCC Using the Science Practice of Conceptual Modeling

CCC: Models	0 to +	– to +	0 to –	Both at –	Finished at 0
Students	302, 303		301, 304, 305, 307, 308, 311, 312, 314, 317		306, 309, 310, 313, 315, 316

Note. Each number refers to a single student's ID number. In the pre- and post-test, two of the three models in the pre- and post-test were included in the analysis.

Table 55. Students' Pre- and Post-Test Change in Representation of the CCC Using the Science Practice of Scientific Explanation

CCC: Explanation	0 to +	– to +	0 to –	Both at +/–	Decline OR Finished at 0
Students	308		312		301, 302, 303, 304, 305, 306, 307, 309, 310,

	311, 313, 314, 315, 316, 317

Note. Each number refers to a single student's ID number. In the pre- and post-test, one of the two explanations from the pre- and post-test were included in the analysis.

Changes in Students' Homework Models and Explanations During the Unit

The rates of homework completion varied widely for both models and explanations during the unit. One student completed none of the model or explanation assignments that were analyzed, whereas four students (303, 306, 308, and 312) completed all of those assignments.

Table 56. Quality of Students' Representation in Conceptual Models Produced During the Unit

Models			DCI								SP								CCC					
Lesson	**2**	**3**	**4 ***	**4**	**4**	**5**	**8**	**Change?**	**2**	**3**	**4 ***	**4**	**4**	**5**	**8**	**Change?**	**2**	**3**	**4 ***	**4**	**4**	**5**	**8**	**Change?**
301						–		**I**						–		**I**						–		**I**
302	–	+	+	–		+	0	**M**	+	+	–	–		+	–	**S**	0	+	0	0		0	0	**S**
303	–	–	+	+	+	+	0	**G**	–	+	–	–	–	–	+	**M**	0	0	0	0	0	0	0	**S**
304		–	+	–	+	+	0	**M**		–	+	+	+	–	–	**M**		–	+	–	+	+	–	**M**
305	0	–		0	–		–	**G**	0	–		0	–		–	**G**	0	–		0	0		0	**S**
306	–	–	–	–	+	–	0	**S**	+	–	–	0	–	0	–	**S**	0	–	0	0	0	0	0	**S**
307	+	–	–	–			–	**S**	–	–	–	–			–	**S**	+	–	0	–			0	**M**
308	+	–	–	+	+	+	0	**M**	+	–	–	+	+	–	0	**S**	–	–	0	0	0	0	0	**S**
309		–		–		–		**S**		–		–		–		**S**		0		0		0		**S**
310		0			–			**I**		0			–			**I**		0			0			**I**
311	–	–			+		–	**S**	–	+			+		+	**G**	0	0			0		–	**S**
312	+	+	–	0	–	+	–	**M**	–	+	+	–	–	+	–	**M**	–	0	0	–	0	0	0	**S**
313		0		0			–	**G**		–		–			–	**S**		0		0			0	**S**
314		–			–	0	–	**S**		–			–	0	–	**S**		–			0	0	0	**S**
315	–	0		0		–	0	**S**	–	–		0		–	–	**S**	–	–		0		0	0	**S**
316	0					0	0	**S**	0					0	–	**G**	0					0	0	**S**
317								**I**								**I**								**I**

Note. The "change?" column represents general trends in the quality of students' representations for that particular dimension as expressed in a model during the unit. I = insufficient data to establish a trend; G = overall growth; S = general stability. Students needed to have turned in at least three models to be categorized as having a trend, and growth required more of the models to have a higher quality code. An asterisk (*) under the lesson name indicates that that model was part of the in-class questions and not the homework assignment. Students highlighted in a gray row are further discussed in following sections.

In the analysis of whether students' during the unit models and explanations improved it was required for students to have completed at least three of the models or explanations to establish a trend. Those with fewer than three models or explanations were coded as being incomplete, "I", for determining change. For a student to have shown growth in any particular dimension, the models or explanations completed toward the end of the unit needed to have a higher score than those completed at the beginning. Students whose work met these requirements were coded as "G" in the "change?" column of Table 56 and Table 57. Consistent scores were coded as "S," or stable. Finally, quite a few students' scores were extremely variable; these students with mixed performances were coded with an "M." In Table 56 and Table 57, each entry represents the code that a student's response received for one model for one dimension. A student received a "0" if there was no evidence of that dimension in the model, a "–" if there was weak or implicit evidence of a dimension, and a "+" if there was strong and labeled evidence of a dimension. For each dimension, a student might earn a particular code in multiple ways. For a more thorough discussion of the coding methods, see chapter 3.

Students expressed their understanding of the DCI using both the science practice of modeling and scientific explanation. Using models to express their understanding of the DCI, three students showed growth, four students had mixed results, seven students' understandings were stable, and three students submitted insufficient work to establish a trend. For the scientific explanations, only one student showed growth in representing the DCI, five students had mixed results, five students had stable results, and six students submitted insufficient work.

For the SP of modeling, most students used the practice at least weakly throughout the curricular unit. Only a few earned "0," and no student earned "0" exclusively. Two students showed growth in their modeling, both moving from an absent to a weak understanding of the practice. For scientific explanation, again most students had a weak understanding of the practice; one student showed growth, moving from an absent to a weak understanding of the practice. For the practice of scientific explanation, five students earned an absent understanding exclusively.

For the CCC, only six students showed reference to the CCC in two or more models. The CCC was generally not represented in students' models. Only models 2 and 3 focused on a broad scale view of watersheds, which meant that it would be much more difficult for students to include the CCC in the later models. For explanations, only one student included reference to the CCC in one explanation.

Table 57. Quality of Students' Representation in Scientific Explanations Produced During the Unit

Explanations	**DCI**						**SP**						**CCC**					
Lesson	2	3	4	5	6	Change?	2	3	4	5	6	Change?	2	3	4	5	6	Change?
301	–			0		I	–			0		I	0			0		I
302	–		+	0	0	M	+		+	–	+	S	0		0	0	0	S
303	0	0	+	0	–	M	–	0	–	–	–	S	0	0	0	0	0	S
304	0		+	–	–	M	–		–	–	–	S	0		0	0	0	S
305	–	–		0	–	S	–	–		0	–	S	0	0		0	0	S
306	–	0	+	+	0	M	+	–	–	–	–	S	0	0	0	0	0	S
307	–	0	–	0	–	S	–	–	–	+	0	S	0	0	0	0	0	S
308	0	0	–	0	–	S	0	–	–	–	–	G	0	0	0	0	0	S
309						I						I						I
310	0	0				I	0	–				I	0	0				I
311		0		–	–	G		–		0	+	M		0		0	0	S
312	–	0	+	0	–	M	–	+	–	–	–	S	0	–	0	0	0	S
313		0		0	0	S		0		0	0	S		0		0	0	S
314				0	0	I				0	0	I				0	0	I
315				–	0	I				0	0	I				0	0	I
316		0		0	0	S		0		0	0	S		0		0	0	S
317						I						I						I

Note. The "change?" column represents general trends in the quality of students' representations for that particular dimension as expressed in a model during the unit. I = insufficient data to establish a trend; G = overall growth; S = general stability. Students needed to have turned in at least three models to be categorized as having a trend, and growth required more of the models to have a higher-quality code. Students highlighted in a gray row are further discussed in following sections.

Summary of Changes in Students' Homework Models and Explanations During the Unit

Most students (11 for models, 10 for explanations) had either mixed or stable representations of their knowledge of the DCI in models and explanations during the unit. Six students turned in less than three of the assignments and thus had insufficient submissions of explanations to establish a trend. Many students may have had inconsistent representations during the unit because of the change in DCI. After lesson 3, the unit shifted to a more microscopic level of understanding of water flow. As a result, students may have had difficulty representing some of the key components of the concept in their models and explanations.

Integration in Students' Responses

The preceding sections examined the students' represented understandings of the content and practices by each dimension for the pre-test, for the post-test, and unit assignments. Although these sections make it appear that the dimensions were being considered in isolation, it is impossible to consider any of the dimensions without considering portions of the others, because of the interconnectedness of the dimensions in the representations. For example, the CCC represents a broader theme that can be applied to the DCI. Therefore, an understanding of the CCC related to this performance expectation is intrinsically associated with the DCI. Similarly, students' facility with the SP is related to their understanding of the DCI and CCC. For example, a student who understands where water moves on the surface of the Earth, but has not fully clarified an understanding of the mechanism for the movement, will have difficulty explaining the mechanism in a labeled illustration. It is possible to use a CCC or SP expertly in expressing an inaccurate understanding of the DCI, so knowledge of one dimension is not necessarily an indication of knowledge of another dimension, as is shown in some of the following examples. The previous sections examined students' growth according to the represented dimension, but that growth cannot be considered outside the context of the other dimensions.

The inherent integration of the dimensions makes an argument for the importance of evaluating the students' representations (models and explanations) using an approach that accounts for all three of the dimensions together. With an examination of students' responses to the pre- and post-test models and explanations, it is possible to aggregate students' work from each of the three dimensions into an integration score that accounts for the presence or absence of each of the dimensions in these particular representations. In the following tables, the student scores for each of the dimensions are coded as weak or thorough in the pre- and post-test, with an additional column that shows the number of dimensions that are represented in the student's models or explanation. For each dimension, the students' highest score is recorded, regardless of whether that score occurred in the same model as the other dimensions. Therefore, a 3 on the post-test does not necessarily mean that the student represented all three dimensions in a single model, but it does mean that the dimensions were included across the student's two post-test models. The integration scores are not intended to represent a students' capacity to integrate, since students respond differentially according to the assessment prompt (this finding is examined more closely in the next section).

In the post-test models, 10 students had three dimensions represented, and two students had two dimensions represented. In Table 58, six students started with no dimensions represented in the pre-test models, and six students had one dimension represented. Five students had two dimensions represented in their pre-test models. The remaining four students can be classified as having not integrated models, representing one or no dimensions. Overall, 12 of the 17 students in this section represented an integrated understanding in their post-test models. There is much variation in the integration columns, and these scores represent the students' highest achievement.

Table 58. Integration as Represented in Students' Pre- and Post-Test Conceptual Models

Models	**DCI**		**SP**		**CCC**		**Integration**	
Student	Pre	Post	Pre	Post	Pre	Post	Pre	Post
301	0	–	–	+	0	–	**1**	**3**
302	0	+	–	–	0	+	**1**	**3**
303	0	–	–	–	0	+	**1**	**3**
304	0	–	–	+	0	–	**1**	**3**
305	0	–	0	+	0	–	**0**	**3**
306	–	0	–	–	0	0	**2**	**1**
307	–	–	–	–	0	–	**2**	**3**
308	0	–	0	+	0	–	**0**	**3**
309	–	0	–	0	0	0	**2**	**0**
310	0	–	–	+	0	0	**1**	**2**
311	0	–	–	+	0	–	**1**	**3**
312	–	+	–	–	0	–	**2**	**3**
313	0	–	0	–	0	0	**0**	**2**
314	–	–	–	–	0	–	**2**	**3**
315	0	0	0	0	0	0	**0**	**0**
316	0	0	0	–	0	0	**0**	**1**
317	0	–	0	–	0	–	**0**	**3**

Note. For each dimensions, students received a code to indicate that the dimension was absent ("0"), weak ("–"), or thoroughly ("+") represented in the model. The integration columns indicate the presence or absence of information for the three dimensions: a 3 or 2 represent a weak or thorough presence of three or two of the dimensions (respectively) in the representation, and a 0 represents the absence of any of the dimensions.

The students' scientific explanations did not have any examples of three dimensions integrated on either the pre- or post-test. On the pre-test, four students had two dimensions represented in their scientific explanations, and on the post-test that number increased to seven. Interestingly, only one of the four students who had an integrated pre-test explanation also had an integrated post-test explanation. Ten of the students in the section had scientific explanations that were not integrated for the post-test, representing only one or none of the dimensions. The students who had two dimensions represented in their post-test explanations were a subset of the students who had represented three dimensions in their post-test models.

Table 59. Integration as Represented in Students' Pre- and Post-Test Scientific Explanations

Explan.	**DCI**		**SP**		**CCC**		**Integration**	
Student	Pre	Post	Pre	Post	Pre	Post	Pre	Post
301	0	–	0	–	0	0	**0**	**2**
302	0	+	+	+	0	0	**1**	**2**
303	0	–	0	+	0	0	**0**	**2**
304	–	–	–	–	0	0	**2**	**2**
305	0	–	0	–	0	0	**0**	**2**
306	–	0	+	–	0	0	**2**	**1**
307	–	0	+	–	0	0	**2**	**1**
308	0	0	–	+	0	+	**1**	**1**
309	0	0	0	0	0	0	**0**	**0**
310	0	0	–	+	0	0	**1**	**1**
311	0	–	+	–	0	0	**1**	**2**
312	0	0	–	–	0	–	**1**	**2**
313	0	0	0	0	0	0	**0**	**0**
314	0	0	–	+	–	0	**2**	**1**
315	0	0	0	0	0	0	**0**	**0**
316	0	0	0	–	0	0	**0**	**1**
317	0	0	0	+	0	0	**0**	**1**

Note. For each dimensions, students received a code to indicate that the dimension was absent ("0"), weak ("–"), or thoroughly ("+") represented in the explanation. The integration columns indicate the presence or absence of information for the three dimensions: a 3 or 2 represent a weak or thorough presence of three or two of the dimensions (respectively) in the representation, and a 0 represents the absence of any of the dimensions.

Tables 60 and 61 were created with the information presented in Tables 58 and 59, respectively, to determine the number of dimensions that were included in each of the submitted models and scientific explanations. In Table 60, only one student's models showed growth in the number of dimensions over time. Most students had either a mixed or a stable number of dimensions over time. Most students integrated at least two dimensions for most of their submissions. Most of the few 0s and 1s were accounted for by only a few students. Quite a few students included three dimensions, with model 3 having seven examples of three-dimensional representations. The prompt for this model did not explicitly integrate the three dimensions, but the prompt for the previous model homework assignment did integrate the three dimensions explicitly. Eleven of the 17 students developed a three-dimensional model at some point during the unit. Five of the six students who did not have a model that included three dimensions completed three or less of the seven assignments.

Table 60. Integration as Represented in Students' Conceptual Models During the Unit

Models	Integration							
Lesson	**2**	**3**	**4 ***	**4**	**4**	**5**	**8**	**Change?**
301						3		**I**
302	2	3	2	2		2	1	**M**
303	2	2	2	2	2	2	1	**S**
304		3	3	3	3	3	2	**S**
305	0	3		0	2		2	**M**
306	2	3	2	1	2	1	1	**M**
307	3	3	2	3			2	**M**
308	3	3	2	2	2	2	0	**M**
309		2		2		2		**S**
310		0			2			**I**
311	2	2			2		3	**G**
312	3	2	2	3	2	2	2	**S**
313		1		1			2	**S**
314		3			2	0	2	**S**
315	3	2		0		2	1	**S**
316	0					0	1	**S**
317								**I**

In Table 61, the observations from the pre- and post-test explanations hold true for the scientific explanations completed during the unit. None of the students' work shows any examples of scientific explanations that include three dimensions. Ten of the 17 students completed a two-dimensional scientific explanation at some point during the unit. Here, five of the seven students who did not have an explanation with two dimensions completed two or fewer of the assigned scientific explanations.

Table 61. Integration as Represented in Students' Scientific Explanations During the Unit

Explanations	**Integration**					
Lesson	2	3	4	5	6	Change?
301	2			0		I
302	2		2	1	1	M
303	1	0	2	1	2	M
304	1		2	2	2	G
305	2	2		0	2	M
306	2	1	2	2	1	M
307	2	1	2	1	1	M
308	0	1	2	1	2	M
309						I
310	0	1				I
311		1		1	2	G
312	2	2	2	1	2	M
313		0		0	0	S
314				0	0	I
315				1	0	I
316		0		0	0	S
317						I

The following sections give two illustrations of the difficulty in separating the three dimensions so that they can be considered separately. First, the responses of two students using two different SPs (modeling and scientific explanation) completed in the same time period are compared, with very different conclusions reached. Using just one of the two SPs could lead to a different understanding of the student's knowledge related to the DCI. Next, the responses of two students completed before and after lesson 3 are compared, with very different understandings seen after they experienced the same lesson. One student used models to convey his present integrated understanding, whereas the other student consistently conveyed the same understanding whenever she saw a similar prompt. Again, using only the students' representations could lead to a different conclusion about their learning than using multiple sources.

Conceptual Model/Explanation Pairs – Different Information From the Same Time

When we examine the most integrated model and one of the least integrated explanations—that is, the model and explanation that followed lesson 3 (coding represented in

Changes in Students' Homework Models and Explanations During the Unit)—it is somewhat surprising that the most integrated model was not the one with a tri-dimensionally integrated prompt. After lesson 3, in an effort to encourage more students to submit their work, the teacher changed the way in which scientific explanations were submitted.

The prompts for these two activities (scientific explanation and conceptual model) were worded and presented differently. The scientific explanation prompt was, "Write a scientific explanation that answers the scientific question, How big can a watershed be?" This left the students' approach to answering open, allowing the response to be quantitative or qualitative, and not specifying the information that the students should consider when answering. The conceptual model prompt was more specific about what the response should look like, and it included two parts that the students could address: "Draw a conceptual model showing how water interacts with the watershed. Make sure to include how big the watershed is and what influences where the water goes. Label all parts." Although the prompts were directed at the same concept—what determines where the watershed boundary is located—the model prompt included more detail about what the student could include in the response. The conceptual-model prompt gave students the option to show how big the watershed was or what influenced where the water went, and still address at least part of the prompt.

Student 308

The effect of the prompts on the students' responses is very visible. In Figure 13 on the left (also written below), student 308's response to the explanation prompt did not include specific information about the mechanism of the movement of water but focused on the space around the bodies of water.

> *Claim: A watershed can be really big like as big as a continent.*
>
> *Evidence: A watershed can be big because there are bodies of water (rivers, creeks, and lakes mostly) that are far apart from each other, which is a watershed.*
>
> *Reasoning: Not all bodies of water are close together.*
>
> (Student 308; lesson 3, scientific explanation)

In the model, on the other hand, the student showed water flowing from mountains to bodies of water—the downhill flow of water. Neither of the student's responses focused on where the watershed boundary was located, which was not specifically stated in the explanation prompt or in the model prompt. She also showed one body of water connecting with another, indicating a potential connection to nested systems. In this example, the prompt from the model, which suggested that the student include information about what influences where the water goes, seemed to give the student greater freedom to include information she had learned in class that might be related to the answer.

Although this student did not thoroughly represent content related to watersheds in either the explanation or the conceptual model, she was slightly more effective at conveying key concepts in the model. Her model earned a partial representation of the content for all three dimensions: downhill flow of water (DCI), nested systems (CCC), and movement without a clear mechanism (SP). For the explanation, she made a claim and supported it with evidence, but the reasoning was not directly related to the claim, so she earned a partial representation of the practice of scientific explanation (SP). The explanation did not include any reference to the key ideas from class, or to the content of watersheds, earning an absent understanding for both the DCI and the CCC.

On the basis of the examples from student 308, it appears that a combination of the particular prompt and the SP allowed her to more successfully represent her understanding of watersheds in the conceptual model. How the synthesis activities were worded proved to be especially important for the types of information that students provided. The model prompt included more specifics about what could be included, and those elements are seen in the model. Because the model in Figure 13 includes additional information, this model is categorized as tri-dimensionally integrated, despite its being a weak understanding of the content (DCI and CCC). Student 312's model and explanation are included as a contrasting example.

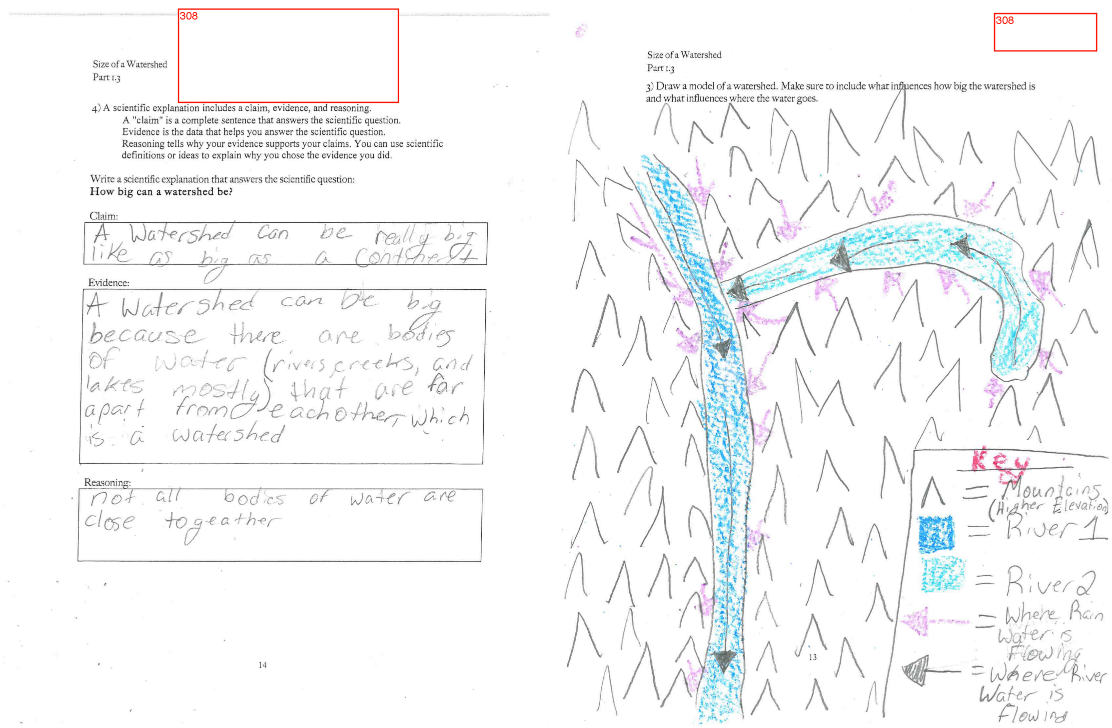


Figure 13. Student 308's explanation and model for lesson 3. The explanation does not include specific discussion of any of the watershed concepts, whereas the conceptual model includes reference to nested watersheds and the movement of water relative to elevation.

Student 312

In contrast to the previous students, student 312 successfully included some content information in her scientific explanation. Not only did she include examples taken from experiences in class as her evidence but she also tied it together using part of the class definition as her reasoning. In her scientific explanation, student 312 included references to nested systems—a component of the CCC:

> *Claim: A watershed can be as big as the biggest body of water, which is probably one of the oceans.*
>
> *Evidence: The Atlantic Ocean is connected to the Gulf of Mexico and the Gulf of Mexico has eight or nine watersheds, so the Atlantic could have at least 10 in the US.*
>
> *Reasoning: A watershed's definition is an area of land, but the result of that watershed can be called a watershed, too.*
>
> (Student 312; lesson 3, scientific explanation)

This explanation's reference to nested systems occurred when the student (inaccurately) described the number of watersheds that make up the Atlantic Ocean's watershed. She also mentioned, in the reasoning section, that where the watershed goes is also called a watershed, making another reference to nested systems. Because she didn't explicitly describe them as nested systems, or state that watersheds are made up of smaller watersheds, this represents a partial understanding of the CCC element nested systems. None of the components of the DCI are included in this explanation. As a result, it earned a thorough understanding of the SP and a weak understanding of the CCC. The conceptual model, on the other hand, conveyed almost an opposite understanding.

Student 312's conceptual model (Figure 14) included a thorough understanding of the DCI and no reference to the CCC. The conceptual model depicted a mountain that served as the dividing point for water. The model showed that, depending on where the water hit the mountain, it could end up in any of four water bodies. To support this representation, the student included rain clouds, the elevation of the mountain, and the elevations of the rivers. Interestingly, the geographic information represented was entirely inaccurate, as no single mountain could send water to her local river, the Missouri, the Mississippi, or the Rio Grande, but the concept that a single, high-elevation point divides the destination of the water is accurate, which earned her a thorough understanding of the role of elevation in determining the destination of water. The representation showed movement as well as the mechanism for the flow of water, earning her a thorough understanding of the SP also. She did not refer to the location of a border for the watersheds or nested systems, earning an absent understanding for the CCC.

Summary of Conceptual Model/Explanation Pairs

In the first example, although student 308 did not successfully include any content information related to the concept of watersheds in her explanation, she was able to successfully represent content in her model. Student 312 was able to partially describe the relationship between watersheds in her explanation, and she showed elevation as a dividing point for watersheds in her model.

In these examples, students 308 and 312 seemed to show different types of information in the different types of representations. Student 308 represented less content related to the science concept in her explanation, but the model prompt seemed to provide her a greater opportunity to represent her understanding. Student 312 showed promise in both representations, although her model seemed to represent the content more precisely. She was able to show one of the components of the CCC in each representation, although they were different components in each. These models and explanations show how students did not consistently demonstrate the same quality of understanding in their models and explanations. This can also be seen when comparing the understanding of the DCI as expressed in a model with a scientific explanation (Table 56, p. 120, and Table 57, p. 122).

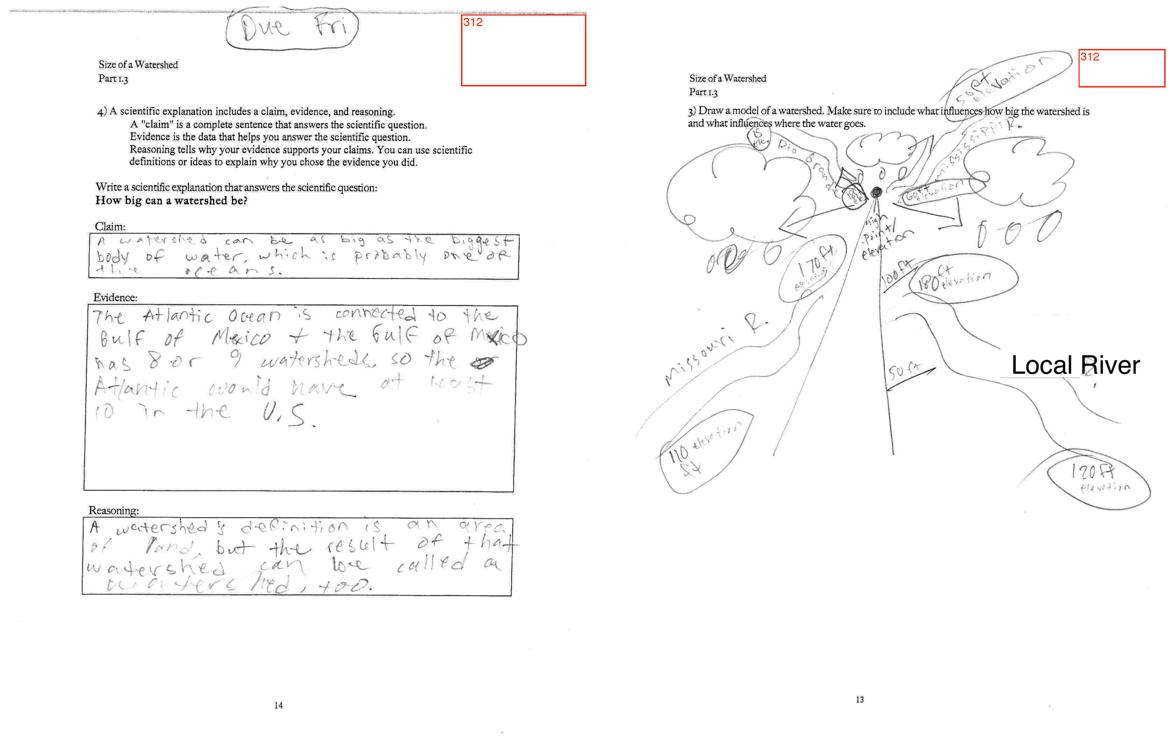


Figure 14. Student 312's explanation and model for lesson 3. The explanation included reference to nested watersheds, describing how eight or nine watersheds make up the Atlantic Ocean watershed. The model focused on a high point as the dividing factor for the destination of water, without focusing on the size of the watershed or the boundary.

Students' Metacognition About Changing Understandings

Students were interviewed four times during the course of the unit. The first interview focused on their understanding of how elevation can be represented in two dimensions, such as on a flat map. Because this interview did not focus on the movement of water, the responses were not aligned with the standard. In subsequent interviews, students were asked about the models and explanations they had recently created. In addition to being asked what they were showing in the current model, students were asked how this model was different from earlier models. Students' responses varied considerably. Some focused on the elements that they included: "Oh, well, this is more simple, I guess, 'cause it . . . I guess, I didn't do like underground and stuff in this one." Others focused on the way in which their understanding of the concept had changed over time. Students 302 and 311 were interesting in that they were able to metacognitively reflect on their understanding during the unit. The following representations of students' changing understanding are based on how the students described their changing understandings in interviews, and analysis of how the models changed using the previously described rubric for student work (Appendix E, p. 242).

The Case of Student 302

Student 302 was an 8th-grade boy who began with very little knowledge of watersheds. He is highlighted here because the ways in which he demonstrated his understandings in his models and explanations made the changes in his understanding very visible. His pre- and post-test explanations of whether the Mediterranean Sea has a watershed show very different understandings (see Table 38, p.107, and Table 39, p.107). In his pre-test explanation, he used evidence and reasoning to describe why the Mediterranean Sea does not have a watershed. He said,

> *From what I understand about watersheds (which is basically nothing), watersheds are part of water purification plants, and from what I understand about the geography of the Mediterranean Sea (which is also basically nothing), there are no water purification plants near the Mediterranean Sea.*
>
> – Student 302 (Pre-test explanation 2; 9/27/12)

During the course of the unit, his represented understanding about watersheds changed, as can be seen in his post-test explanation, which demonstrated a very different understanding, as described in the analysis given earlier. In the second interview, he was asked how his representations in models 2 and 3 (see Figure 15 and Figure 16) were different from one another.

In reflecting on his different conceptual models, student 302 described not only how the representations looked different but also how his understanding had changed. This was seen particularly in his second turn of talk (Table 62), where he described that he initially thought the watershed was the water but later realized that it was the land that the water drained from. Interestingly, he did not mention the addition of a watershed boundary and areas of high elevation that serve as the border of a watershed in his second model (Table 62). He was clear about what he saw as a significant change in his understanding—the transition from focusing on the bodies of water to focusing on the land from which the water drains.

Interview 3 focused on the student's representation of water moving through Earth's surface materials, but in interview 4 (Table 63), the discussion returned to his understanding of watersheds and how it had evolved during the unit. By this point, he remembered his pre-test model without prompting but did not discuss this change in understanding. His responses focused on the change that occurred during the unit as a whole, focusing on his initial understanding of a water tank in a shed. Most likely, his lack of reference to previous class models was related to the emphasis on the “last model” in the question that was asked as a follow-up question.

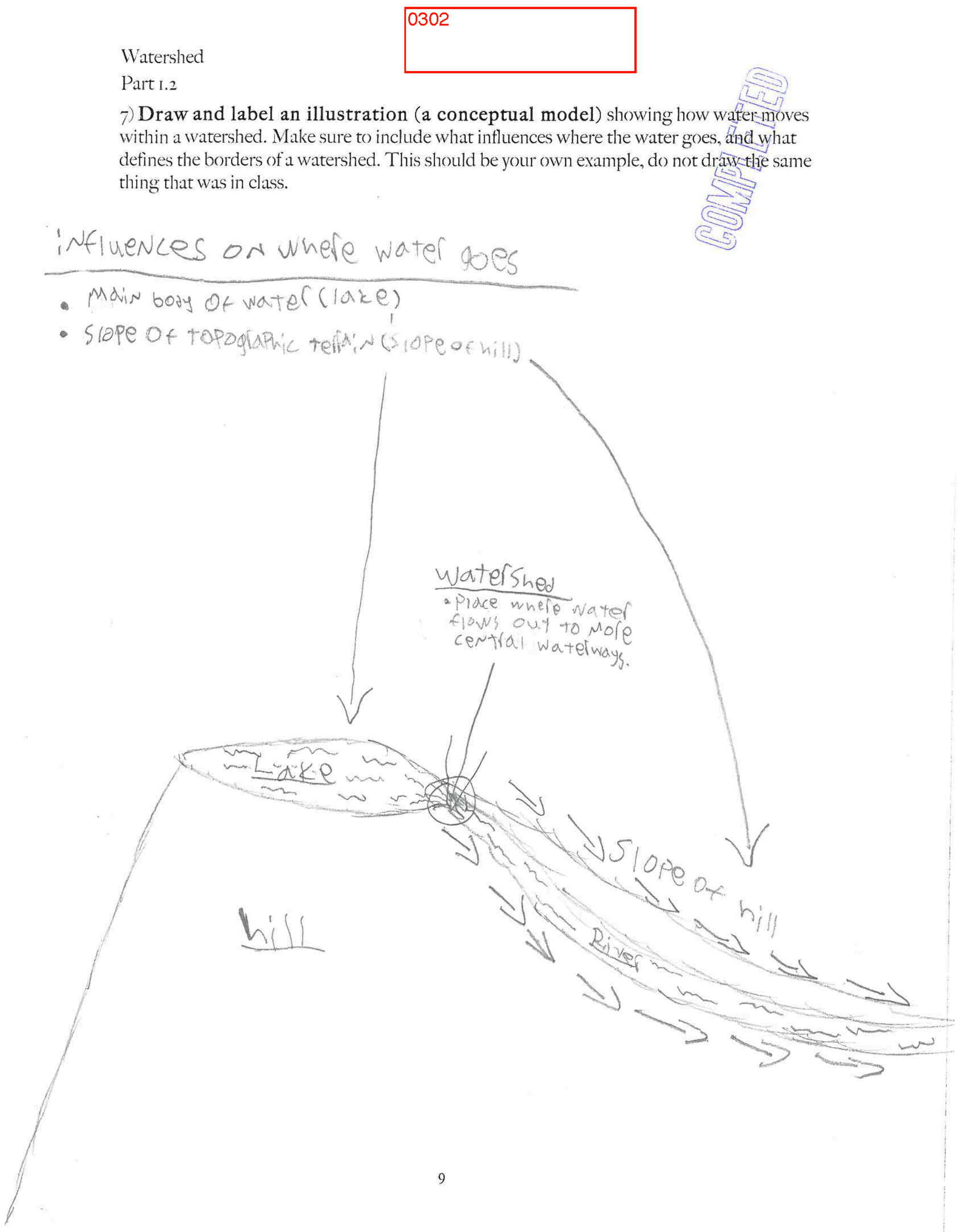


Figure 15. Student 302’s conceptual model of a watershed after lesson 2. He did well in labeling the parts of his model and highlighting the important functional components of the process.

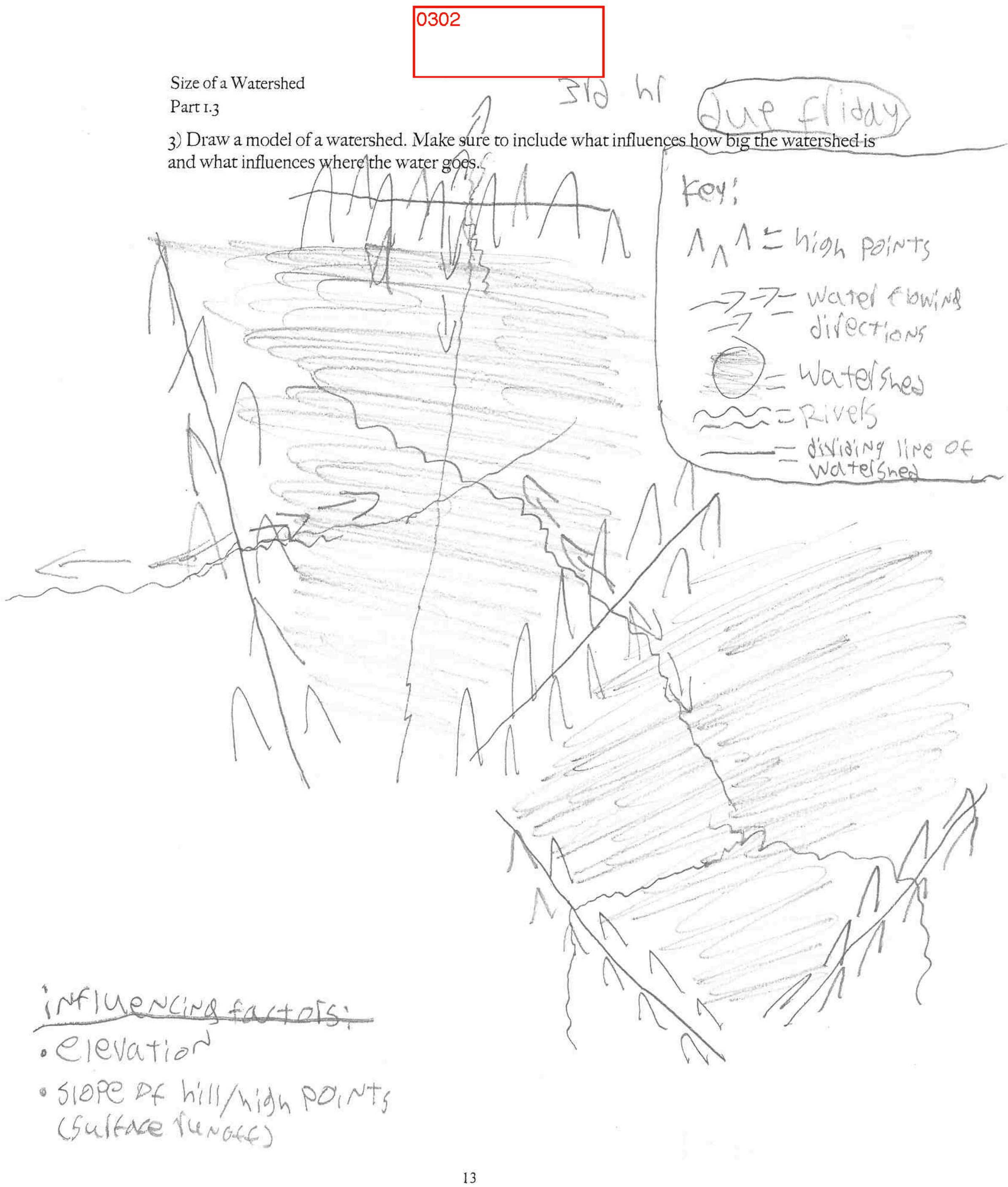


Figure 16. Student 302’s conceptual model of a watershed after lesson 3. As in Figure 15, he described the important processes well. He also clearly identified each component of the watershed by using a key.

Table 62. Student 302 Interview: Reflection on Differences in His Lesson 2 and Lesson 3 Conceptual Models

Speaker	Dialogue
Interviewer	So, looking at your model previous to that, these had very similar questions, but you had different drawings. So tell me a little bit about how the one drawing is different from the other.
302	Well, the drawing I just discussed was after I had learned the true definition of a watershed. Before I wasn't really sure what a watershed was. So I just drew a hill and a lake on the on top of the hill and then where the hill started where the slope of the hill started there was a little creek slash river flowing down the hill and I thought and before I thought the place where that lake started flowing into that river was a watershed cause it was the place where the water flows out to more central waterways. So, I thought that the main body of water, which would be the lake, and the slope of the topographic terrain, and the hill would all influence where the water went. So, I suppose, I was pretty close.
Interviewer	But it's interesting that your water was on the top of the elevation before, and now it's on the bottom of the elevation, right?
302	Yeah, and before I thought that the watershed was the water and now I know the watershed is the land.
Interviewer	These are excellent contrasting ideas of watersheds. Tell me a little bit more about *why* [spoken emphasis on word] they're different from one another?
302	Um well this one the I understood most of the same things for each of these drawings about what a watershed was but what changed in my understanding was with this drawing, the one I discussed earlier, there I knew, I learned that the watershed was actually the area of land instead of the actual water and I made sure to include that in this drawing as opposed to this drawing. (Student 302, interview 2; 10/23/12)

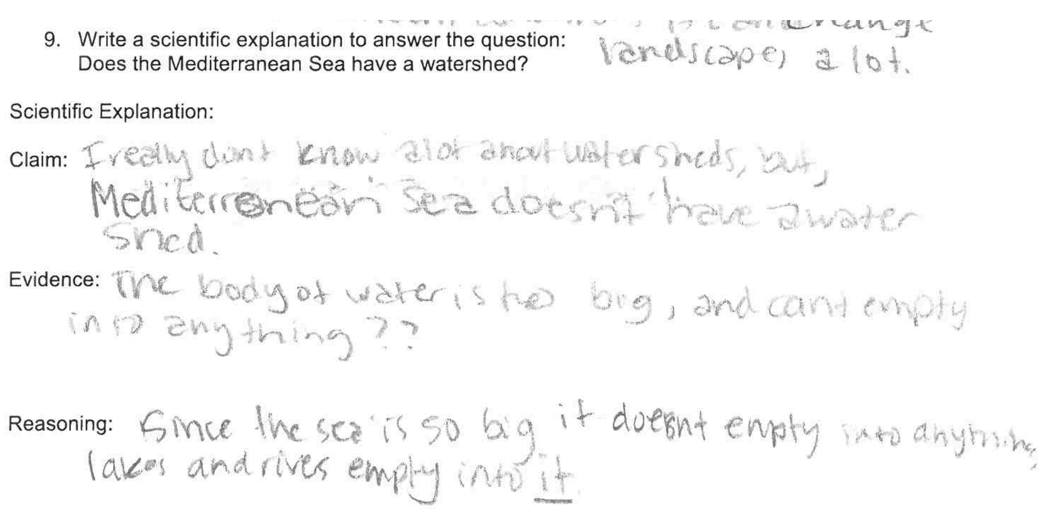
Table 63. Student 302 Interview: Reflection on Differences in His Understanding Between the Pre- and Post-Test

Speaker	Dialogue
Interviewer	Awesome. How was this model different from earlier models?
302	I think for my earlier models—you mean like the last time I took this test?
Interviewer	Or, any of the models in between. What are you doing differently here than before?
302	The last time I took this test I believe I drew a house with a bucket of water in it. So, my understanding of watersheds has evolved greatly since the beginning of this unit.
Interviewer	Awesome. How about from a more recent model? Do you think that this is different from maybe the last model that you drew before this?
302	There were some different questions asked, so I think it was a little bit different, but the ideas I used to draw the model stayed the same for the most part except for the beginning of the unit when I drew a house with a bucket of water in it (Student 302, interview 4; 11/27/12)

The Case of Student 311

Whereas student 302 showed definite growth in his understanding about the class concepts, which he described in the interviews, student 311 had a much less clear trajectory of growth. Student 311, a 7th-grade girl, was mentioned earlier in the section about integrated discussions. She was selected because she was very engaged in class discussion. She was the instigator of the discussions about whether the ocean has a watershed, as highlighted in the classroom discussion excerpts. She completed almost all of the classroom assignments on time and was an engaged member of the class. Despite this, her models changed very little during the course of the unit. Her pre- and post-test models and explanations represent different understandings, but the models she produced during the unit are remarkably similar.

Student 311's participation in class sometimes focused on her confusion about whether an ocean has a watershed. Her difficulty with this component of the concept was evident in her pre-test explanation response (Figure 17), which began with a clarification statement, hedging the remainder of her response, and her evidence and reasoning showed her confusion about the concept. As evidence, she wrote, "The body of water is too big, and can't empty into anything??" As reasoning, she wrote, "Since the sea is so big it doesn't empty into anything; lakes and rivers empty into it." This confusion over whether the source of the water or the destination of the water defines a watershed reflects her confusion about whether an ocean can have a watershed.


9. Write a scientific explanation to answer the question: Does the Mediterranean Sea have a watershed?

landscape a lot.

Scientific Explanation:

Claim: I really dont know alot about watersheds, but, Mediterranean Sea doesnt have a water shed.

Evidence: The body of water is too big, and cant empty into anything??

Reasoning: Since the sea is so big it doesnt empty into anything, lakes and rives empty into it

Figure 17. Student 311's scientific explanation for pre-test explanation 2. Although she claimed to be unfamiliar with watersheds, she did seem to believe that they are related to the destination of the body of water. Thus, what seems to determine whether an area is a watershed is where the water goes next.

Throughout the unit, student 311 drew her conceptual models very similarly. For example, the two models produced after lesson 2 (Figure 18, left) and lesson 3 (Figure 18, right) are very similar. They both show water flowing from areas of land at high elevations to bodies of water at lower elevations. The only clear difference in understanding is seen in the model drawn after lesson 3, on the right. In that conceptual model, the student added streams and minor bodies of water. Both models also depict rain falling only in areas of high elevation. Two of her models on the post-test show almost the same representation; her representation for model 2 is included (see Figure 19).

Her post-test response to explanation 2 (see Figure 20) was markedly different from the pre-test response (see Figure 17). In the post-test explanation, her confusion about the output of watersheds seems to have been clarified. Her use of the precise language from the definition reflects reasoning, but it also makes it difficult to know how much of the concept she understands. In her own words, she describes only that watersheds are made of larger and smaller bodies of water.

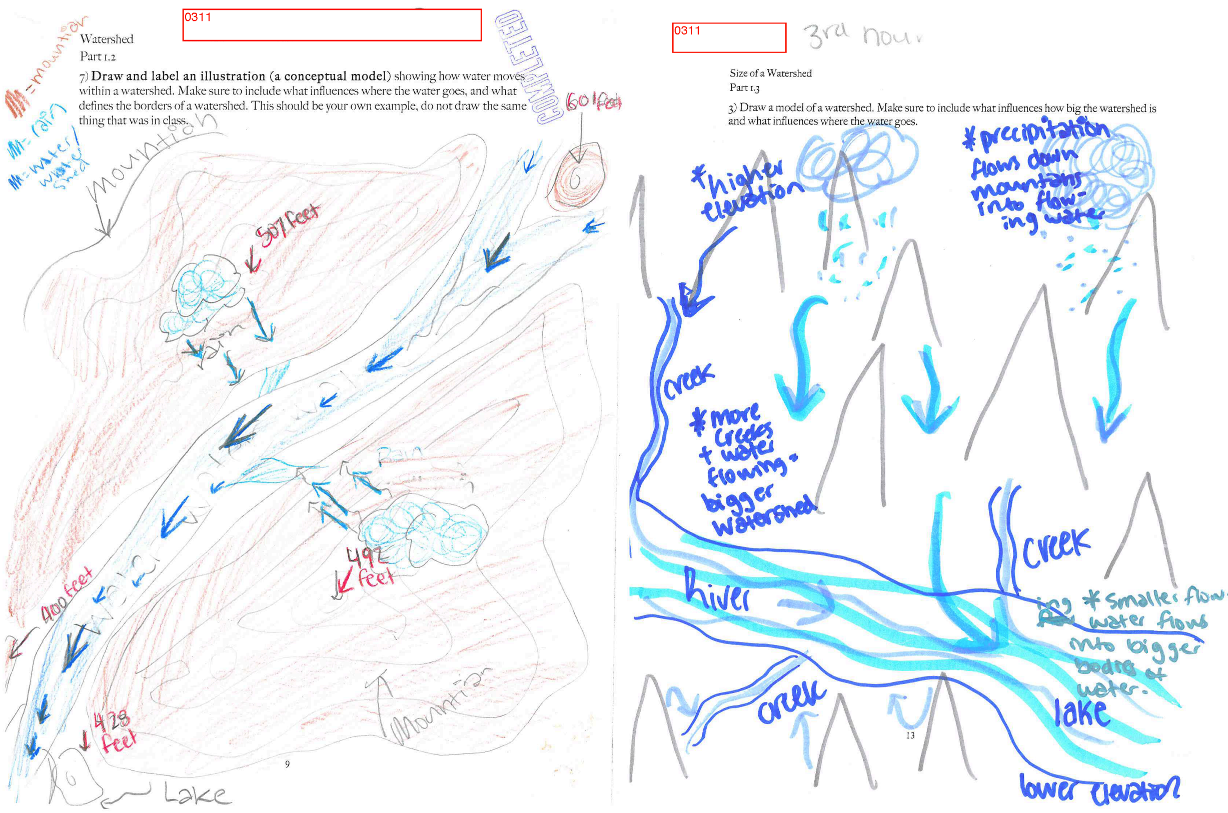


Figure 18. Conceptual models created by student 311 during the unit. The model on the left was completed after lesson 2, and the model on the right after lesson 3. Although she used different forms to convey the information, both models show very similar information. The notable difference is that the model on the right adds creeks flowing into the river.

In the interview about her post-test representations (see Table 64), student 311 was flustered by the questions and had trouble explaining the concepts in her own words. When asked about the relationship between the smaller bodies of water and the larger bodies of water, she said that she had memorized the definition but had since forgotten it. She also mentioned that over time, drawing a watershed became easier and easier as she began to “get familiar with the steps of drawing the watershed, it just flows out instead of, like, 'Oh, crap, what do I have to do?'" (Student 311, interview 4; 11/28/12) She also mentioned that she might have added other things to her model to better represent her changing understanding, such as an ocean. It seems that by the end of the unit, student 311 was still struggling to make sense of the science content. Her representations are well labeled, but the mechanism for the watershed is not always clearly represented. This may represent an area of her confusion, but it is unclear whether the lack of understanding led to the less clear model.

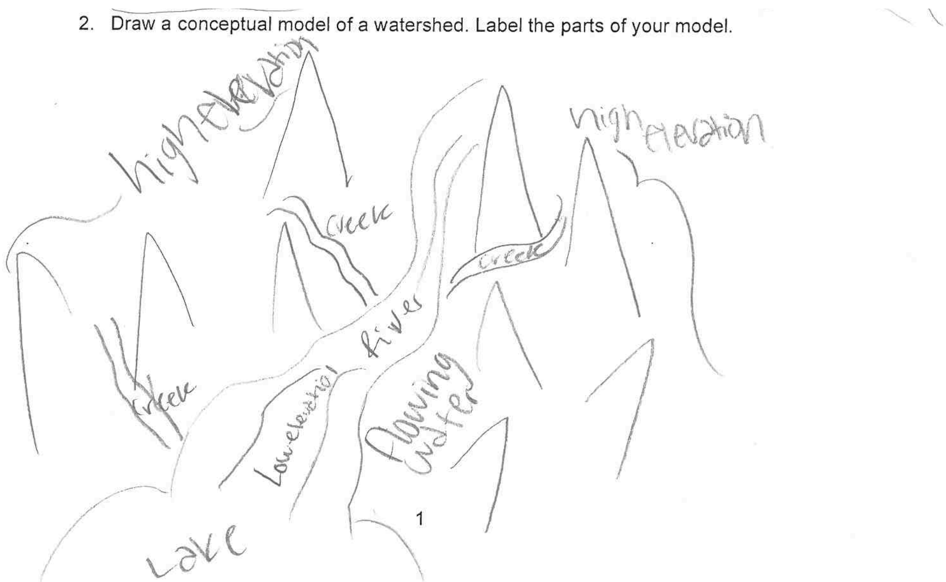


Figure 19. Post-test model 2 produced by student 311. This model includes water flowing from areas of high elevation (labeled) to areas of low elevation (labeled). This representation is very similar to both the lesson 2 and lesson 3 models, shown in Figure 25.

Claim: The Mediterranean Sea has a water shed.

Evidence: I learned in class that as long as a body of water has smaller flowing bodies of water coming into it, it is part of a water.

Reasoning: A water shed is an area of land which water flows into bigge bodies of water, and is divided by elevation. Enough said.

Figure 20. Student 311's post-test scientific explanation for explanation 2. In the post-test, she definitively answered the question and applied knowledge from class as evidence. Her reasoning was strong for the definition that the group built during the class period.

Table 64. Student 311 Interview: Reflection on Change in Representations and Understanding Between Pre- and Post-Test

Speaker	Dialogue
Interviewer	How is this model different from earlier models that you drew?
311	Well, earlier models, I didn't really get that–I thought that they had to always be surrounded by land. That's what I got until the last segment of our unit. I guess it's just I drew more of the water going into the watershed. I kind of drew it so it could be surrounded by water. Well, this example is surrounded by land; but I would have drawn a bigger body of water that just has parts of land, maybe a continent or something. Then water flowing into.
Interviewer	You said that before, you thought that it always had to be surrounded by land. What do you mean by that?
311	Well, it's divided by elevation. I thought that meant that higher elevation had to just cover the whole thing, and then make a giant bowl for it; but, instead, it can just be any smaller body of water going into a bigger one.
Interviewer	Okay. The watershed is the area–I guess I'm a little bit confused by how the smaller body of water plays into the bigger body of water. How are they related?
311	Well–crap–I don't know that. I forgot the definition. I had memorized it. It just has to–I guess you can't have a watershed–it's confusing. It's hard to explain. Can you repeat the question?
Interviewer	Okay. You said that there can be a smaller body of water that is related to the bigger body of water. How are they related?
311	Well, that smaller body of water has to be flowing. It has to be moving; and it has to have higher elevation around it, so it can go down the mountains or whatever and collect in a certain area to move. Then it has to go into a bigger body of water, because that's just the natural way of the watersheds. It won't get skinnier and then die out. It will have to go and collect somewhere. It has to go somewhere once it's divided by elevation.
Interviewer	Awesome. Is the smaller body of water part of the watershed of the bigger body of water?
311	Yeah. I guess there can be stagnant pools or ponds of something, but then there's nothing flowing into it. That just means that the precipitation, it just is pooled up. It doesn't really have–I don't know. It doesn't have anything going into it, so it's just kind of sitting there. It doesn't play any part in any other things. It just sits there and then evaporates eventually; or doesn't and just–it doesn't have anything to it besides just water. There's no cycle with it.
Interviewer	Okay, awesome. You just told me how this model is different from earlier models. Why is it different?
311	Well, I guess, I just understand it more. I've made more drawings of this and we talked about it in class. I guess I just understand more. There are things I could have added to this that I didn't think of it at the time because I'm not good with on-the-spot tests or something.
Interviewer	What would you have added?
311	I would have added a giant body of water, like an ocean or something. Then had the lake and then another river from the lake going in.
Interviewer	Awesome. You said that this model represents a better understanding of the concepts than the earlier ones. Is there anything that you–
311	Well, I don't actually–it's not better because I think they were all kind of the same. I think it could have been better, but it's better than the first ones. Then when it comes into when you get familiar with the steps of drawing the watershed, it just flows out instead of, like, "Oh, crap, what do I have to do?" I didn't get this part in class or didn't understand this and you have a test in front of you. Then you can kind of draw it easier.
Interviewer	Nice. Is there–what on this drawing shows a different understanding than earlier drawings?

311	Well, mine–this is why I wish I had put an ocean into it. If I had an ocean on this one, it would have showed that it doesn't have to be surrounded by water. It just has to have higher elevation for other parts to go into the bigger body of water. (Student 311, interview 4; 11/28/12)

Other Students' Reflections on Learning During Lesson 3

Students 302 and 311 are somewhat extreme cases in this particular class section. No other student had quite as dramatic a shift in understanding that was as well described in the interview as student 302. And no other student had as little change in the models while actively participating in class discussion, and describing a changed understanding, as student 311. Although these levels of changed (and unchanged) representations were unusual, other students also described lesson 3 as being influential to their understanding. In the second interview, which occurred after lesson 3, students were shown their models from after lesson 2 and after lesson 3. The prompts for these two models were very similar but not identical (see Table 14, p. 66, for the text and dimension analyses of the prompts). In the interview, students were asked to describe the more recent model, and then they were shown the lesson 2 model. They were told that the prompts were similar, and asked first how their models were different, and then "why are these models different?" Some students described the differences in their models superficially. When asked why the models were different, three of the six students attributed the difference to in-class activities or discussions.

The students' responses to the question about why their models were different are shown (Table 65). Only six of the 10 interview students participated in the second interview. The students who participated in the second and third interviews were chosen because they had completed the homework assignments to be discussed in the interview. (All 10 of the interview students participated in the first and fourth interviews.) In response to the question about why the students' models were different from one another, two students said that their understanding of the concept had changed, without discussing where they learned new information (Table 65: students 302 and 307). Three other students said that their second model reflected what they had talked about in class: student 311 attributed it to something the teacher had told them, student 308 said the teacher "had showed them what a watershed was," and the third student said that his model showed "what we talked about in class… it will come down from higher elevation to lower [elevation]." Student 312 mentioned that her father had told her what to draw for the lesson 2 model, but she had not wanted to erase her whole model and start over, so she kept her initial drawing. She drew what he had told her to draw for her lesson 3 model though.

Table 65. Interview Students' Responses to a Prompt About Why Their Lesson 2 and Lesson 3 Conceptual Models are Different

Speaker	Dialogue	Attribution of Change
302	Um well this one… I understood most of the same things for each of these drawings, about what a watershed was, but what changed in my understanding was with this drawing, the one I discussed earlier, there I knew. I learned that the watershed was actually the area of land instead of the actual water, and I made sure to include that in this drawing as opposed to this drawing.	Learned New Information
306	Maybe it was because they don't say the exact same thing and stuff. So I was gonna do this, cause that's a watershed cause that's what I think it is, and mountains and stuff. Here, cause that's kinda what we talked about in class, where it will come down from higher elevation to lower [elevation].	Discussion in Class
308	Alright, so my first drawing, I just kind of looked up the definition of a watershed in definition dot com, and this is what I thought it meant, but later on, during Science, [Teacher Name] showed us what a watershed was, what a watershed actually is, so that changed my idea of what a watershed is.	Classroom Activity
307	Just… I thought it was just the water that comes down from higher elevation, so that's what's here, but here I understood that it comes from higher elevation, but it's also the piece that it's going into bigger bodies of water, and that's another piece of it, so drawing those two together made it more realistic I guess.	Different Understanding
311	Um, well, the first one that we did I did with topography lines cause that's what I thought we were supposed to do, but then I found that it was just that we had to make a representation of elevation, so I just did an easier way and wrote mountains instead of having to have all the exact um feet and all that to go down…	Changed Understanding of Expectations
	For the second one, [Teacher name] had explained how um it could be, as I said before, any body of water, as long as it has something going into it and I learned that it always has to be flowing, and it can't start like at the top it can't flow certain ways cause every watershed has to have like a point or a starting position, I guess.	Discussion in Class
312	Because it's a… well my dad told me this before, but then I kind of kept it this way, cause then I would have like had to erase everything. On one side of the river it would mostly go this way, over to this one side of the mountain instead of… and then, unless the river was on both sides of the mountain it wouldn't have gone to both. It wouldn't have gone to the same river. (Interview 2; 10/24/12)	Father's Instruction

Most students said that their models represented change in their understandings. Five of the six students said that new information they had learned led to a different representation. This indicates that the students' changed models were not the result of pure chance or a different feeling about the information on the different days. However, although students described new understandings, these did not always translate to very different models and representations. For example, student 311's representations stayed very stable when prompted with a similar prompt throughout the curricular unit, even though she described a changed understanding in the interview.

Summary of Students' Metacognition During the Unit

Students 302 and 311 completed almost every assignment during the unit, but their outcomes were very different. Student 302 seemed to represent many different aspects of his understanding using a conceptual model. Although student 311 labeled most elements in her conceptual models, she did not consistently show what caused the processes. Student 311 also seemed to leave out parts that were unclear to her, whereas student 302 included elements that he later determined to be less accurate. Student 311 seemed to rely more heavily on the class-generated definition than 302 did. Although student 302 used the phrase "divided by elevation," the remainder of his reasoning seemed to be his own words. Whereas student 302's representations changed to reflect his new understandings, student 311 consistently used very similar representations throughout the unit, modifying them very little after lesson 2. As a result, student 311 seemed to change her representation very little over time, compared with the extreme changes seen in student 302's representation for this particular content.

Although student 311's representations changed very little, she described a changed understanding in the interview. Similarly, five of the six focal interview students described having changed their understanding between lesson 2 and lesson 3. Of those five students, three described classroom activity as influencing their understanding.

Summary of the Change in Students' Expression of an Integrated Understanding of the Concept During the Unit

In the pre-test to post-test comparison, most students presented at least a weak understanding for the DCI, SPs, and CCC in either a model or explanation. Specifically, 13 of 17 students represented at least a weak understanding of the DCI; 15 of 17 students represented a weak or thorough understanding of the SP of modeling; 14 of 17 students represented a weak or thorough understanding of the SP of scientific explanation; and 11 of 17 students included a weak or thorough reference to the CCC in their post-test model. During the unit, most students had mixed results on their models (11 of 17 students) and explanations (10 of 17 students).

Given the shift in content (moving from macro to micro scale), this might be expected, but few patterns of growth were observed.

Comparisons between student 308's and student 312's models and explanations reveal that students might have provided different information when using different SPs. Although the prompts were slightly different from one another, it could be that similar prompts using different SPs do not elicit the same knowledge.

Students 302 and 311 revealed differences in student understanding. Student 302 began the unit with a strong use of the SPs, which he used to reveal his understanding of the content. Sufficient information was gathered to begin to see where his understanding might deviate from the normative understanding. During the unit, 302's representations of the content shifted as his (self-described) understanding changed, and then remained stable. Student 311's representations shifted earlier and differed from the pre-test to lesson 2. For the remainder of the unit, she represented similar contents and seemed to rely heavily on the class definition to support her understanding.

Overall, five of the six interview students described change in their models as related to a change in their understanding that occurred between completing model 2 and completing model 3 (Table 65). Three of the six students attributed the change in the models to activities that occurred during class. Although students described a better understanding, most of their understanding of the DCI decreased or remained stable in their models during this time, but a weak understanding of the CCC was added that may not have been previously represented (Table 56, p. 120).

Did the Enacted Curricular Unit Correlate With Change in Expressed Understanding?

The written curricular unit and classroom dialogue provided students with opportunities to integrate the three dimensions during the curricular unit. Most of the prompts throughout the curricular unit explicitly incorporated two of the three dimensions. The majority of these questions focused on integrating the DCI with the SP. Three questions during the unit explicitly integrated all three dimensions. Unfortunately, the work from two of these three questions was not collected. The third question fell during lesson 2, which preceded any explicit discussion of the CCC in class. Students showed the most integrated responses in the model assignment after lesson 3. In those models, 8 of the 17 students had at least a weak understanding of the CCC, as compared with seven students who had no understanding of the CCC. The remaining two students did not complete the assignment.

Although most lessons and prompts implicitly integrated the CCC into the dialogue, lessons 3, 4, and 9 included these components more explicitly. The activities added to lesson 3 by the teacher, in particular, explicitly integrated new information related to components of the CCC, into students' prior understandings of watersheds. This lesson led to at least four students' being metacognitively aware of the change in their own understanding of the concept. Although not all students were interviewed during this time, a large number of students went from an absent understanding of the CCC to a weak understanding, as represented in their models during this time.

The classroom activities that occurred during lesson 3 were a mix of teacher-developed activities to support students' understandings and those that were part of the original written curricular unit. One of the teacher-developed activities was modeling the identification of watershed boundaries. This activity was intended to be a part of the students' activities in lesson 2. The questions were intended to guide the students to the conclusions they reached in this modeling activity. The activity did not reach the intended depth of understanding, so it was incorporated into lesson 3 with a more directed approach, and supplemented with examples that supported students in identifying and confronting misconceptions about water flow (Table 29 and Table 30, p. 90). Ultimately, four of the six focal interview students attributed the change in their understanding seen between model 2 and model 3 to learning that occurred between lesson 2 and lesson 3.

The classroom discussion provided students with opportunities to integrate by participating in integrative dialogue and by observing modeled integration. The teacher tried to integrate the classroom conversation by reminding students of the activity prompt, giving directions, asking questions, and making integrative statements. In lesson 3, the teacher made integrative statements and asked integrative questions to support students in making sense of their data analysis, and he also modeled activities to support students' engagement with the data analysis. Lesson 3 included the greatest number of explicit opportunities for students to integrate

the three dimensions. Both the teacher and the students initiated integrative conversations in this lesson. This was also when the greatest change in students' representations was seen.
How students could represent their understanding with conceptual modeling was only briefly discussed in class (see Table 33, p. 95, for a typical example). How and why they might want to use the SP was generally focused on the homework assignment and the requirements for the assignment.

How students used the class experiences to represent their understandings varied. Students 302 and 311 represented their understandings very differently in models 2 and 3. For example, student 311 consistently drew very similar versions of a watershed throughout the curricular unit, while simultaneously being active and engaged in class, asking questions and participating in class discussions. Though her understanding changed, as she described in her interview, her representations did not change very much. Students did not seem to understand what was important in their representations, as was seen in all four of the presented cases (302, 308, 311, and 312). It could be argued that this was not the case for 302, but despite his representations' having significantly changed, his own perception of what was different contrasted with what was seen to be the greatest change. In another example, students referred to a boundary without mentioning why the boundary was there (e.g., Figure 12). Their exclusion of the reason for the boundary showed that they were missing an understanding of either the content or the purpose of the practice, which was to explain why the processes occur as they do. One student (302) with a strong understanding of the SPs was able to metacognitively reflect on his learning, which may have been easier for him because of the thorough representations he developed.

Although some students also seemed to learn content related to the DCI during the second half of the unit (Table 56, p.120, and Table 57, p. 122), it was difficult to relate this learning to the CCC, because many of the concepts discussed could be loosely described as part of the CCC. Keeping a strict definition of the CCC meant that much less of that section of the unit was interpreted as tri-dimensionally integrated.

Chapter 5

Discussion and Implications

Introduction

This chapter revisits the findings of the study. It focuses on how the enacted curricular unit provided students with opportunities to gain an integrated understanding of the performance expectation, and on the learning that occurred in conjunction with the curricular unit. This review of the findings also describes ways that the research contributes to the literature by adding to or extending previous research. One particular gap identified in Chapter 2 is the lack of literature that offers possibilities for including the crosscutting concept (CCC) into the curricular unit. This review explores how the findings contribute to answering the following research questions:

- In what ways did the enacted curricular unit make an integrated understanding of the concept available to students to learn?
- Did students' expression of their integrated understandings change during the course of the unit? If so, in what ways did their expressed understandings change?

Summary of Findings

Research Question 1: Ways That the Enacted Curricular Unit Made an Integrated Understanding of the Concept Available to Students to Learn

Opportunities to Integrate From the Written Curricular Unit

The written curricular unit included activity descriptions and question prompts intended to support students' development of integrated understandings of the content. A post-enactment analysis of the curricular prompts revealed that most prompts included two of the three dimensions of science education, most often the disciplinary core idea (DCI) and science practice (SP). The CCC was implicitly included in several of the prompts but explicitly included in only three of them. Schwartz and colleagues' (2004) findings showed that explicit support for pre-service teachers to develop their understanding of the nature of science helped most students to develop *their* understanding. Here, students received few explicit opportunities to integrate the CCC, and only some students were able to do so. The prompts that implicitly included the CCC required the students to use the CCC to answer the question thoroughly, but few students made the connection. It was only at the end of the unit that students were explicitly asked to connect their understanding of the DCI and SPs to the CCC.

The intention was to include the CCC implicitly throughout the curricular unit, hoping that students would start to recognize the components of the CCC when they were explicitly discussed. However, it was impossible to entirely separate the dimensions for analysis, as they are intricately interwoven. Even when students assessed the DCI, it was through their ability to represent it using an SP, or through their knowledge of the CCC as represented in a model (SP) of this DCI. Although the model and explanation prompts were developed to be similar, slight variations in the wording elicited different information from different students, as was seen when comparing the model and explanation responses for students 308 and 312. These two students represented very different understandings of the DCI when asked to do similar tasks using a different SP. The fact that the CCC components were not explicitly discussed during the curriculum reinforces the findings of other authors that an explicit approach might be more effective in supporting students' development of contextualized knowledge (Roseman, Linn, & Koppal, 2008; Schwartz, Lederman, & Crawford, 2004).

Opportunities to Integrate From the Enacted Curricular Unit

The written curricular unit prescribed neither the content nor the format of the classroom discussions. An analysis of the discussions revealed that most instances of integration focused on discussion of the DCI in the context of an SP. The integration of DCIs with SPs has been well studied, with many research projects looking at effective curricular units for developing students' knowledge of science content in the context of SPs (Lehrer & Schauble, 2006; McNeill, Lizotte, Krajcik, & Marx, 2006; Songer 2006). This work builds on that research, looking at the integration of those two dimensions, and including the CCC when possible. Lessons 3 and 4 integrated the CCC into discussion of the DCI and SP as a third dimension. Here, the CCC seemed to come up in the context of the need for clarification of confusing components of the DCI. In one case, a student brought up a point of confusion related to the CCC, while the teacher guiding the discussion initiated other examples. Lesson 9 was designed as a synthesis lesson in which students might be able to think about what they had learned in the context of the CCC of systems. The goal was for students to use prior knowledge of other content areas to develop an understanding of what a system was, and then to apply that knowledge to their understanding of the system of watersheds.

Throughout the lessons, the greatest proportion of tri-dimensionally integrative dialogue was in the form of integrative statements made by the teacher. These statements could be seen as teacher talk that serves as verbal supports for students' development of new practices (McNeill & Krajcik, 2008; Songer, Shah, & Fick, 2013). The work of Songer, Shah, and Fick in particular focuses on the verbal scaffolds teachers use to support students' development of content knowledge in the context of the science practice of scientific explanation. In that work, Songer and colleagues see the verbal supports as specific to the curricular unit the teachers are working with, and complementary to the written scaffolds included in the written student notebook. The verbal supports were provided to support students in being able to develop explanations, based on observed difficulty. Here, the students are working to integrate three dimensions, and the teacher, observing students' difficulty with particular aspects of the assignments, provides students with verbal support for developing an integrated understanding and integrated representations of the content. The integrative statements made by the teacher, as well as the class discussions the teacher supported the development of, can therefore be seen as the verbal support for the written curricular unit. These findings are similar to the work of Songer and colleagues (2013) in that the teacher was seen to use classroom dialogue to alter the curriculum to support students' learning. This case is different from their findings in that the scale on which the verbal supports occurred is very different. Here the teacher added lengthy classroom discussions and new activities, while Songer and colleagues (2013) found the teacher to use supportive phrases.

In the enacted curricular unit, many integrative conversations and activities were designed to support students' development of their knowledge of the DCI and its integration with the SP, and ultimately with the CCC. The choice of the topic relative to the DCI was intended to implicitly integrate the CCC, because watersheds are an example of a system related to the flow of water on Earth's surface. In the enactment of lesson 3 in particular, the teacher developed activities and discussions that provided students with opportunities to share their thinking about the concept, and to bring to light students' misconceptions. Revealing students' misconceptions about a particular DCI is an important part of the learning process. When the teacher understands students' prior knowledge, he or she can support students in making sense of new information (Piaget & Inhelder, 1969/2000). For example, when the teacher drew a chain of water bodies and asked students to predict the direction of water flow, as well as to explain why it would flow that way, the students' misconceptions were revealed. They had argued that the water's destination might be a marsh. Only after evaporation rates were discussed were students convinced the water would flow in the other direction.

In the coding of the CCC, the students' representations of the CCC were not independent of the DCI. As the CCC is applied to a particular DCI a thorough representation of the CCC becomes dependent on a thorough understanding of the DCI. Therefore, it is possible for students to integrate the CCC without a thorough reference to the DCI, but these weak incorporations are unlikely to lead to the goals of using the CCCs. The *NGSS* suggest incorporating the CCC as a tool for helping students make sense of new information and for making connections across science disciplines (NGSS Lead States, 2013). In some class discussions, the CCC was used to clarify points of confusion. For example, to clarify whether an ocean could have a watershed, student 311 asked about the destination of water from the watershed. Student 311's questions approached the CCC from a similar perspective without being prompted to do so, thus exposing the potential for this use of the CCC.

Research Question 2: Change in Students' Expression of an Integrated Understanding of the Concept

Students' Understanding as Represented in the Pre- and Post-Test

Most students in the class improved in their understanding of both the DCI and the SP from the pre-test to the post-test. Some students also improved in their understanding of the CCC, but these examples were seen more in their models than in their explanations. Most students (13 of 17) represented a better quality of understanding of the DCI on the post-test than on the pre-test. More students were able to show a better quality of understanding of the DCI using models than using scientific explanation on the post-test. Thirteen students showed at least a weak understanding of the DCI on their post-test models, whereas only six students showed at least a weak understanding of the DCI on their post-test explanations.

In terms of the SPs, 8 of 17 students improved in their use of the practice of scientific explanation, and 14 of 17 students showed at least a weak understanding of the practice on their post-test. The findings related to students' development of the practice of scientific explanation initially appeared to differ from the work of McNeill (McNeill et al., 2006) and Songer (Songer 2006), which showed that middle school students need specific instruction and scaffolds to successfully develop scientific explanations. Clearly, students made progress in their ability to make claims and support their claims with evidence, but few of them effectively used reasoning to justify their explanations. Although several of the students in the class had prior experience with explanations (5 months before this unit began), there was little instruction to support students' development of the practices during the unit, and the students' pre-test achievement should account for prior knowledge of the practice. In this study, students were able to work with the structural support of the claim, evidence, and reasoning framework for constructing scientific explanations (McNeill et al., 2006; Songer, 2006), but they received little instruction about what qualifies as evidence or reasoning.

Fifteen of the 17 students showed at least a weak understanding of the practice of modeling in the post-test, but they had started with a higher level of understanding with this practice. Eleven of the 17 students had a weak understanding of the practice of modeling on the pre-test. These findings, which are related to students' ability to represent the DCI using the SP of modeling, are similar to the findings of Lehrer and Schauble (2000), which showed that over time, and as students gained familiarity with disciplinary content, their ability to represent that content in models improved. For example, many of the students here started with the basic mechanism— that water flows downhill—but over time, they modified their representation to better show the intricacies of the process, and, with the added complexity, they were able to show that areas with higher elevation divided the flow of water and sent it to different destinations. Whereas Lehrer and Schauble's students developed their models as part of the in-class instruction, these 17 students completed the work as homework and received little instruction around the practice of modeling.

Many students' use of the CCC also improved between the pre-test and the post-test. Only one of the 17 students referred to the CCC in either the pre-test model or the explanation, but in the post-test, 11 of the 17 students referred to the CCC on either the model or in the explanations. Focusing on students' integration of the dimensions is particularly important when examining their understanding of the CCC. The *NGSS* emphasize the importance of not assessing students' knowledge of the components of the CCC absent the context of the DCI (NGSS Lead States, 2013), and here we examine students' knowledge of the CCC as it relates to the DCI in the context of an SP. These three components are bound together. Not all students improved their use of the CCC, but the CCC is a new component that relies heavily on students' knowledge of the other dimensions.

When the dimensions are examined individually, students appeared to improve during the unit, but when they are examined together, the information changes. The preceding paragraphs seem to separate the dimensions into separate discussions, but independent analysis of the dimensions changes the picture of the students' growth. Although students improved in each of the dimensions, a better picture of their understanding can be gained when pairs of dimensions are considered. The students made progress in their ability to develop a scientific explanation (14 of 17 students showed at least a weak understanding of the practice of scientific explanation), but only 6 of the 17 students included pertinent information related to the DCI in their explanation. On the other hand, 11 of the 17 students presented information related to the DCI in their models.

Students' Understanding as Represented in Models and Explanations During the Unit

The following section describes change in students' achievement during the curricular unit. Although students' achievement can be said to be inconsistent, some of this inconsistency may be related to differences in the complexity of the curricular prompts. The difficulty of the curricular prompts was not assessed, so differences in students' ability as represented by any pair of prompts may relate to differences in the way the prompt was worded or what the prompt asked students to do in order to respond to the prompt. For more information, see the Validity section (p. 58).

Differences in students' represented understanding at a particular time point were analyzed and revealed inconsistency in the information that students provided during a single time period across the type of prompts. For example, a student may represent more information related to the DCI and CCC in a model than in an explanation, whereas another student may use the explanation to represent more content than the model. Differences in the information that students represented can be seen in the triangulation tables, included in Appendix F (p. 252). More students provided an integrated response on the lesson 3 model than on any other conceptual model prompt during the curricular unit. During this same time period, students completed the lesson 3 scientific explanation prompt, which was the least integrated explanation. In the case of student 308, only information related to class content was provided in her model, whereas student 312 provided related but inconsistent information in both her model and explanation. These two avenues for understanding students' knowledge related to the science content were both productive in eliciting information, but they varied in the type and quality of information elicited.

Most students (11 of 17 for models; 10 of 17 for explanations) had inconsistent results during the unit. Individual students' understandings did not seem to consistently grow during the unit, and both growth and decline occurred for most students and most dimensions. For example, student 302 began the unit with a strong understanding of the SPs, which may have supported his developing understanding, which he described to have changed significantly between lessons 2 and 3. Student 302 attributed his change in understanding to experiences in class. After lesson 3, his results on classroom models and explanations were much more mixed in the micro-scale content. In the post-test, he once again showed the understanding he represented at the end of lesson 3.

This research extends the findings of other work (Gotwals & Songer, 2010; McNeill & Krajcik, 2011)—specifically, that when students' growth and achievement are tracked during the course of the unit, much fluctuation can be seen in their understanding. McNeill (2011) found that varying the prompts made the responses easier or harder for students, providing them with different opportunities to provide evidence and reasoning. Gotwals and Songer (2010) found that varying the difficulty of the prompts is important for determining where students are in their learning progression. In this present research, some prompts explicitly asked students to include the CCC, whereas others did not allow the possibility of including the components of the CCC being coded for, but instead allowed inclusion of other components that were more difficult to define (e.g., processes and interactions). The components of the CCC that could be more definitively identified in students' models and explanations were more difficult for students to represent in micro-level models and explanations, which made up most of the second part of the unit. This problem was revealed by the students' evident desire to select only examples that concretely represented a component of the CCC; as a result, they found it much more difficult to earn credit for the CCC later in the unit.

On the other hand, student 311 did not change her representation much from lesson 2 to lesson 3 to the post-test: her drawings were similar for each of the similar prompts. She seemed to base her understanding on a memorized definition, which she had difficulty recalling in the post-unit interview, in which she described how the process of modeling became easier over time because she remembered how to draw it from the time before. Student 311 also described things she had learned in class that she realized she did not include in her model. She completed all of the class assignments and described having memorized the definition of a watershed. These findings seem to support the point emphasized in the *NGSS* (National Research Council, 2012), that students gain a better understanding of the SPs when they have been introduced to the reasons for the practice. Student 311 did not seem to understand the purpose of the assignments, and she apparently expended effort on representing what she perceived to be the "right answer" rather than on understanding the practice.

Similar curricular prompts throughout the first part of the unit created tools for students' development of metacognition and seemed effective in supporting students when used with the interview question, but the curricular prompts alone were not enough to help students' metacognitive reflection on their learning. The use of metacognition is seen as an important component of students' long-term retention of connections they make during a learning experience (White & Frederiksen, 1998). As seen in an approach used by Lehrer and Schauble (2000), this work had students regularly revising their models to reflect changes in their understanding of how the phenomena worked. This work is different from that of Lehrer and

Schauble (2000), as they were working with elementary students using physical models of elbows, and the modifications occurred in response to students' questions about similarities to and differences from the real thing. Here, students gained additional experience with the phenomena and were prompted to draw a new representation to account for new understandings gained during the learning experience.

When prompted during the interview to notice change in their models and to reflect on the reasons for the change, five of six interview students did see change in their models, and they attributed it to a modified understanding of the content. This finding initially appeared different from those of others (e.g., Davis, 2003) that showed that students often have difficulty assessing their own understanding. With closer examination, the students' responses suggest that these students similarly had difficulty evaluating changes in their understandings. For example, student 311 believed that her representation had changed, which it had (instead of using topographic lines to show mountains, she had used upside down Vs), but the DCI represented in the model remained consistent. The two illustrations represented very similar understandings. Students were not asked to reflect on how much their understanding had changed. Although the finding does not seem to support an unusual metacognitive ability in these students, it does support the potential for students' metacognitive reflection with some additional prompting. Like the work of Davis (2003) and others, this work supports the idea that, to build metacognition of their own learning, students need prompted opportunities for reflection.

The approach that student 311 took during the unit seems to align more closely with traditional views of learning than with the more reform-based goals of this curricular unit. In traditional approaches to learning, students often use experiments to confirm information they have already learned, and they strive to recall factual information (National Research Council, 2007). Here, students were encouraged to represent their current understanding of the phenomena, and to apply that knowledge using an SP. The conversations that the teacher developed provided opportunities for students to show their thinking, bringing to light misconceptions (Table 29, p. 90). This was seen in the example watershed that the teacher developed (Table 30, p. 90). Student 311's responses to the model prompts indicate an application of traditional learning values to the curricular materials. This indicates that students may need additional support to understand not only the content and practice goals of the unit but also how to learn scientifically, through the development of knowledge.

Implications

Opportunities for Curriculum Development

Supporting Students' Development of the Use of Science Practices to Represent Their Understanding of Content

Although many opportunities to use SPs existed, students often needed more support to understand what made one model or explanation more effective than another. Most students completed the unit with at least a weak ability to use the SPs (15 of 17 for models, 14 of 17 for scientific explanations), but many students were using a weak representation of the practice (nine students for models, eight for explanations). For the practice of modeling and for scientific explanations, a weak use of the practice indicated that they were not sufficiently supporting their claims with reasoning.

Many researchers have focused on the supports that students need for their development of an SP during the course of a curricular unit (Lehrer & Schauble, 2000; McNeill, Lizotte, Krajcik, & Marx, 2006; Songer 2006), although much of this research has focused on students' understanding as expressed through prompts that vary during the course of the curricular unit. This research focuses on students' representing their emerging understandings of a concept to convey their changing understanding of the phenomenon. Like Lehrer and Schauble's work (2000), this research indicates that using consistent prompts for an SP shows promise for eliciting students' changing understanding, but that additional research is needed to understand how to support the development of individual students' practice to better represent their in-the-moment understanding of the concept.

This work has implications for using the SPs to record students' understandings related to the DCI during a unit. Additional research is needed to determine how best to support students in their development of the use of the SPs without influencing the students' representations of their understandings. Students may need support with their use of the practice outside the DCI being taught, in a way that does not influence their representing their own understanding in a model or explanation. Students may also need general feedback about their representations that supports their development of the practice without questioning their understanding. Applying Lehrer and Schauble's (2000) approach, group critique of a representation might support students' use of the

SPs, but it is unclear what effect students' telling one another what to include would have on their representations of their understandings.

Supporting Students' Development of Metacognition Through the Use of Consistent Curricular Prompts

Most opportunities to integrate in the written curriculum focused on integration of the DCI with the SP. To support students' metacognitive reflection about how their understanding of the three dimensions changed over time, students needed more opportunities to see their understanding of the relationship between the DCI and the CCC change over time. The model and explanation prompts alone did not appear to develop students' metacognition about their learning, nor did the prompts alone influence students to represent their in-the-moment understanding of the phenomenon. A few students represented only the parts of the phenomenon they were sure about, not representing those components they were uncertain about. Any metacognition observed in this research was related to students' use of the models and explanations to respond to interview questions about change in the representations and change in their understanding. The interview prompts provided students with opportunities to describe the differences in their representations and their understandings.

Based on the students' metacognitive reflection in response to the interview questions, it appears that adding a process of metacognitive reflection to the prompts in the written curricular unit would provide students with the opportunity to observe and describe differences in their own representations and support students in acknowledging differences in their understandings. This process could support students in noticing new understandings, but the reflective prompts alone are unlikely to support students' recognition of how they might improve their use of the SP. Since the students know what their intended understanding was when they created the representation, they are unlikely to identify where their intended meaning is unclear. White and Frederiksen (2000) incorporated a process of reflection in which they evaluated one another's representations. Building from that work, it might help students to learn the process of modeling to have other students describe what they see represented in the model, and to comment on the components of the class understanding of the phenomena that they do and do not see represented in the model.

This was not true of all of the students. Student 302 was different. In his representation of his in-the-moment understanding of the concept, he included elements he later learned to be inaccurate. All of the written curricular prompts in this unit were similar to what Davis (2003) called activity prompts: those questions that serve to guide students in their participation in a curricular activity. In her research, Davis also included reflection prompts, to support students' metacognitive reflection on their learning and understanding of the material during the unit (Davis, 2003). In addition to developing students' knowledge of the purpose for the science practices, it might have been fruitful to explicitly include, from the beginning, the CCC in the model and explanation prompts. With less variation in the curricular prompt, students would have been able to compare their responses to the identical prompt, eliminating the possibility of variation resulting from the change in the prompt. In addition, students would most likely benefit from the addition of reflective prompts to the written curriculum, providing opportunities to describe whether their models and explanations were different, and why they were different, as they moved through the unit. These reflective prompts would provide students with opportunities to reflect on changes in their understanding that were seen here only because of select students' responses to interview questions. Davis (2003) found that general prompts for reflection supported students more than the very contextualized prompts. This might mean that students would benefit from prompts that provide them with opportunities to think about whether their understanding had changed.

Metacognition about the practice of modeling is what Schwarz and White describe as metamodeling knowledge (Schwarz & White, 2005). Metamodeling knowledge supports students in understanding how and why to apply the practice of modeling (2005). Although the *NGSS* (NGSS Lead States, 2013) did not specifically recommend that students be supported in developing metamodeling knowledge, the document did describe the need for students to develop an understanding of the hows and whys of using the SPs. Prompting students for general reflection about how their understanding has changed, when using similar prompts throughout a curricular unit, has the possibility for being a very fruitful means of developing metamodeling knowledge.

Supporting Students' Development of Integrated Understandings by Defining the Scale on Which Integration Occurs

The enacted curricular unit included integrative conversations and activities that supported students' thinking. Most opportunities to integrate in the written curricular unit focused on integrating the DCI with an SP, and most instances of integrative dialogue focused on integrating those same dimensions. The occasional instances of the CCC's being incorporated by itself and as a second dimension (Figure 4) indicate that integration between the three dimensions might have been seen more frequently if the focus had been on observing classroom conversations rather than individual statements.

This analysis was based on the assumption that individuals discuss scientific topics by integrating the three dimensions in a single sentence. It focused on examining the classroom conversations at the sentence level, which may have been the wrong grain size for analyzing integrative dialogue. When breaking down qualitative data into segments for analysis, a decision about the grain size of the phenomenon of study (here, the integration of the three dimensions) must be made (Maxwell 2013). Examples of integrative statements and questions occurred, but integrative dialogue seemed to be more common when looking across statements. In this class in particular, the students and the teacher seemed to build on one another's statements to develop meaning, as was clearly seen in the dialogue that occurred between students 308 and 312 as they developed a group definition for watersheds (Table 23, p. 83). Integrative dialogue in a single sentence seems to be much less common.

The Role of CCCs in an Integrated Understanding

The results of this research suggest two different but connected uses for the crosscutting concept. First, the crosscutting concept can be used as a tool for building students' understanding of a DCI, thus supporting the development of deep knowledge of the DCI. Second, the crosscutting concept can be incorporated into students' representations of their understandings (for example, models and explanations) to support the development of connections across DCIs and science disciplines.

In the initial *NGSS* materials, with the draft version of the standards (NGSS Lead States, 2012), it appeared that the CCCs were a separate type of knowledge. This conclusion was based on the way the CCC was presented as separate from and equal to the DCIs and SPs. This conclusion is problematized by the way that the CCC is intrinsically tied to the supplemental information included about the DCI. In the description of the DCI, the standards address the components of the CCC. This leads to the conclusion that these two types of knowledge are interwoven and interconnected. My work supports the view that CCCs are different from the DCI. Because the CCCs are a tool for understanding the DCI, they provide a framework for developing a deeper understanding of the content, and they could also support students in making connections across DCIs and science disciplines.

CCC Problem: Defining the DCI as Independent From the CCC

Defining the CCC for the purpose of locating instances of the CCC in student work proved difficult, which reinforced the idea that the CCCs are a component of the broader category of content knowledge. Determining the boundary between the DCI and the CCC is unclear in the context of a particular standard. CCCs are large-scale concepts, so they are difficult to define in the context of a particular DCI. For this research, the CCC was operationalized by breaking down the written description of the CCC from the *NGSS* to phrases that students could understand, CCC terms or vocabulary. Here, the CCC was operationalized as "boundary," "inputs and outputs," "interactions," and "nested systems." These phrases made the CCC of systems easier to apply across content areas, allowing students to locate components of the concept. Individually, the components did not reflect the true nature of a system as a whole. An additional challenge was that this research focused on the components of the CCC that were more easily identified, eliminating many statements that may have included the CCC because the boundary between the DCI and the CCC was blurry. A hard line was drawn between what does and does not count as part of the CCC, which accounted for only half of the CCCs. Including the other half of the CCC—interactions and inputs/outputs—would have made it much more difficult to identify references to the CCC. Activities were designed to implicitly integrate the CCC, which made distinguishing it from the DCI more difficult.

Here, what counted as evidence of the CCC was much smaller than the actual concept. Students learned pieces of the concept, and it was unclear whether they understood the concept as a whole. This difficulty in defining the boundary between the CCC and the DCI had implications for the ability to determine when work was or was not integrated, and how to incorporate the CCC into curricular units. To further complicate the difficulty, the overlap was blurred in the language of the *NGSS* itself (NGSS Lead States, 2013). The final version of the standard used here had "energy and matter" as the CCC. In the description of the DCI, the details of the standard described the flow of water that resulted from sunlight and gravity, whereas the CCC focused on the transfer of energy. In this context, the transfer of energy was through sunlight and gravity. This indicated that long-term proficiency of the CCCs included the students' ability to describe the CCC independent of a specific system, but the *NGSS* specifically stated that “crosscutting concepts should not be assessed separately from practices or core ideas” (NGSS Lead States, 2013, p. 80). This resulted in what initially appeared to be a conflict for teaching and learning, because the students should have had a deep understanding of the CCC as it related to a particular DCI, and they also should have had a shallow knowledge of the CCC that could be used to probe for a deeper understanding of the DCI. In fact, here it seems that these might not be conflicting ideas. Perhaps the latter knowledge of the CCC might be easily developed in students who did not have prior experience with the CCCs, through the use of readily accessible prompts for students, which they can use to ask questions about the DCI.

CCC Problem: The Relationship Between a Deep Knowledge of the DCI and the CCC

CCCs are difficult to learn because a deep understanding of the CCC is embedded in knowledge of the DCI. As described in the *NGSS* (NGSS Lead States, 2013), it is not intended that students be assessed on knowing the parts of the CCCs; instead, students need to be able to relate them to the DCI. The CCCs are intended to serve as a frame for supporting students’ learning of new material (NGSS Lead States, 2013). Thus, student 311 used the CCC unintentionally, as she had yet to be introduced to the CCC. In lesson 3, she asked questions about the outputs of the water and the nested systems, without having yet been taught those terms. In this instance, it is possible to see the potential for using the CCC as a framework for understanding the DCI.

Making connections such as these requires a deep understanding of the DCI. In the details of the performance expectations in the *NGSS* (NGSS Lead States, 2013), the CCCs served as an overarching theme for the standards. In the standards, the specifics of how the CCCs are applied to a particular performance expectation were described in the detailed information about the DCI. In the detailed information about the CCC, there was no information about how it could be applied to a DCI. This further supported the conclusion that a strong understanding of the DCI was tied to a deep understanding of the CCC. In this study, many of the students’ CCC references were scored as a weak understanding, because the students included a border without any rationale, indicating insufficient familiarity with the DCI to thoroughly describe the reasoning for the CCC.

These findings extended the work of Schwartz, Lederman, and Crawford (2004), who found that the pre-service teachers were supported by explicit opportunities for reflection about the nature of science so as to make gains in their understanding of the process of science

(Schwartz et al., 2004). In this present research, similar implications for the incorporation of the CCC were found. Although students had the opportunity to use the CCC, it was not until the final lesson that it was incorporated explicitly into a lesson. Some students made gains using the CCC, but an explicit inclusion of the components of the CCC might have supported classroom discussion, as well as students' developing understandings related to watersheds. In their work, Schwartz and colleagues asked the pre-service teachers to reflect regularly on their understanding of the work of science, revising their explanations of what science is. This process of revising their understanding was similar to the one used in this present work, although the pre-service teachers in their study knew that they were being assigned internships to experience the process of science (2004).

The curricular unit provided students with several implicit opportunities to integrate the CCC in their models and explanations, but only a few explicit opportunities. The explicit opportunities to integrate the CCC came at the ends of each of the sections in the unit. In future iterations of the curricular unit, students would probably be better supported by the inclusion of more explicit references to the CCC, both in classroom conversations and in the curricular prompts.

CCC Promise: CCCs Could Serve as a Framework for Curriculum Coherence

CCCs could be helpful because they provide students with a framework for thinking about content. Curriculum coherence, a concept discussed by Roseman, Linn, and Koppal (2008), refers to alignment of scientific ideas, connections with the natural world, connections to students' prior knowledge, connections to relevant evidence for the phenomenon, and avoiding unnecessary detail. They described two design approaches that support coherence: learning goals–driven design that always focuses on the relationship between the activities and the learning goals (see also Krajcik, McNeill, and Reiser, 2008), and eliciting and building on students' prior knowledge. Here, we began to think about how the CCCs might promote continuity across the curricular unit. The CCC came up in class discussion in two ways: first, as a frame for clarifying students' confusion around a particular concept, and second, as a synthesis for understanding what the students had just learned. For example, student 311 asked questions to clarify components of the CCC using the CCC as a framework for instruction, supporting coherent understanding of science, and student 302 quickly incorporated components of the CCC into his models. Additionally, lesson 9 was developed to support students' making sense of what they had learned through the lens of the CCC. Roseman, Linn, and Koppal (2008), like Schwartz, Lederman, and Crawford (2004), also stressed the importance of explicit connections.

At least initially, it may have been more difficult for students to include the CCC in an explanation than in a model. Although Lehrer and Schauble (2000) discussed how a model was merely another way to explain a phenomenon, an idea echoed in the *NGSS* (NGSS Lead States, 2013), where models appear as a component of the SP of explanation. In this present work, 11 of the 17 students referred to the CCC in post-test models, and only 2 of the 17 students referred to the CCC in their post-test explanations. These data support the idea that, for this content, it was easier for students to initially represent the CCC in a model than in an explanation. Information from the CCC seemed to most easily fit in a scientific explanation as reasoning, a part of the scientific explanation that most students struggled with. Reasoning was the difference between a weak and a thorough use of the SP of scientific explanation. Thus, students might need additional support to translate the CCC into reasoning to support their scientific explanations. Supporting students to use the CCC as the reasoning for their explanations may be a productive way for students to make connections across disciplines.

This research revealed two ways in which CCCs can be used as tools to support students' developing understanding. Student 311 used the CCC to develop a deeper understanding of the DCI. In class discussion, she asked questions about components of the CCC to clarify her confusion, without knowing that her questions related to the CCCs. Also, connections were being developed in the students' use of the CCC to label components of their illustrations with standard vocabulary. Some students included boundaries (CCC) for their watersheds (DCI) without deep enough knowledge of the DCI to justify the location of the boundary, but those who thoroughly represented the CCC had a deep understanding of the DCI. The vocabulary can be reused when the student is faced with a different system in the future, developing a deeper understanding of the CCC by connecting it to other examples.

It is important to note that the CCC used in this study was not the CCC that was incorporated into the final version of the standard. This change in CCC speaks to the broad application of CCCs as tools for interpreting and deepening students' understanding of the DCIs, and to their potential for supporting students to make connections. The CCC in the final version of the standard was "Energy and Matter," and it is possible to see the usefulness for that CCC can be seen in this content as well. This supports thinking about the CCCs and the SPs similarly.

Although each performance expectation includes a CCC and an SP, it is likely that a variety of CCCs and SPs could be used to support students' development of deep understanding of the DCI.

This research reveals the potential for two distinctly different times for using the CCC in the enactment of an integrated curricular unit. In this study we see evidence in the classroom dialogue for one role, throughout the unit, as a tool for supporting students to clarify and deepen their understanding of the content. While the availability of data about students' work in lesson 9 limits our ability to understand the connections that students' were making with the CCC in the synthesis of the unit, it is possible to see a potential second use of the CCC, at the conclusion of the unit, as a synthesis for supporting students to make connections across science disciplines. Students' use of the CCC in their models, in this case as both justified and unjustified labels of components of the CCC, might support them in making connections across science disciplines. In both of these cases, the CCC could be applied to the context of a particular DCI, which embeds the CCC in the specifics of the DCI.

In both of these potential applications for the CCC it serves as a tool to support students in making connections. The CCC itself is composed of science principles, which can then be applied to specific content. In this application of the principles of the CCC to a particular DCI, not only is the CCC intimately tied to the DCI, but accurate and complete application of the CCC was tied to a deep understanding of the DCI in this circumstance. This research also reveals the potential for using multiple CCCs to support students' thinking. Here we saw how the CCC of systems and system models supported students in developing a deeper understanding of watersheds, but the final version of the standard included the CCC of energy and matter. Both of these CCCs could be used in combination to support students thinking.

Integration as a Means of Assessing Students' Understanding

Integration is difficult to assess because it is impossible to separate the dimensions entirely for analysis, but assessing a whole without reference to knowledge of the three dimensions gives an incomplete picture (Duschl, 2012). The analysis presented here is incomplete without any one of the parts presented. For example, analyzing students' integrated knowledge without the details of the dimensions would not provide details about the students' growth, and many students would appear stagnant when in fact there was considerable growth in their understandings.

The dimensions are intricately interwoven, and although many of the references to the CCC appeared even though not intentionally designed into the curricular unit, it could not be concluded that all the dimensions would organically appear during instruction. This curricular unit was designed to intentionally integrate the DCI with the SPs. The unit could have played out differently, without significant reference to the CCC before lesson 9. When all three dimensions were included, it was difficult to tease one from another, but it was never guaranteed that all three *would* be present. Because the three dimensions were so closely tied, assessment of students' work in one dimension was always related to their knowledge of another dimension. Exceptions to this rule were questions that drew purely on students' understanding of the DCI, without drawing on their understanding of why and how the processes occurred. The CCCs could easily be incorporated into a unit built on the integration of DCIs with CCCs as a framework for asking questions to deepen students' understanding. This same integration would require much more effort in a curricular unit not already built on students learning DCIs integrated with SPs.

In terms of developing a new curricular unit, this research appears to show that the CCC would best be used throughout the lessons, to support students' developing understandings and to help them in their development of questions for investigation. This differs from the study of Bybee (2013), which, in *Translating the NGSS for Classroom Instruction*, suggested that teachers and curriculum developers focus on backgrounding and foregrounding dimensions according to the priorities of the lesson. The findings of the present research imply that a curricular unit might better serve students by focusing on the integration of a DCI with SPs during each lesson, and using the CCC as a frame for asking questions both as a part of class discussion and for investigation. This changes the emphasis from backgrounding and foregrounding to integration throughout the unit.

Further Research

These findings imply four areas for future research: scaffolds to support students' integration, students' developing an understanding of the hows and whys of SPs, the role of the CCC in classroom practice, and how to support teachers' practice for the *NGSS*. Each of these ideas will now be expanded on in the context of this research.

Developing Science Practices

The present research showed that the quality of the curricular prompts affected the support for students' development of integrated understandings and of tri-dimensional representations. One contributing factor to this differential result appeared to be the students' understanding of the purpose of the SPs, and of the hows and whys of the SPs. Incorporating a more explicit focus on students' understanding of the practice should be a priority for supporting their authentic use of the SPs (National Research Council, 2012; NGSS Lead States, 2013). Future iterations of curricular materials should make the meta-knowledge required for the SP more apparent to students. Additional research should examine how students with different understandings of the hows and whys of the SP represent their understandings of the DCI and the CCC, and whether that knowledge about the purpose of the practice improves the potential for using the products of the practices for developing students' metacognition about their own learning and understanding.

Incorporating the CCC

Significant additional research is needed to examine how the CCC might be incorporated into curricular units and enacted curriculum. The present research begins to describe the role of the CCC, but it presents an example of only one unit in a single classroom. Other ways in which the CCC could be integrated into instructional activities should be studied, as well as where and when it should be included. This one example shows how the CCC might be incorporated into instruction as a framework for asking questions to lead to a deeper understanding. In a manner similar to the way SPs can be incorporated into enacted curriculum (Falk & Brodsky, 2014), the CCC could serve as a knowledge-building or as a synthesis activity. Research is also needed to further examine how the CCC might support students in developing stronger understandings of the DCI, and how a strong understanding of the DCI might support developing stronger understandings of the CCC. The present research begins to show how students without explicit instruction about the CCCs incorporate them into their knowledge of the DCI as represented using an SP. Students with explicit instruction might show new and innovative ways of representing their understanding of the CCCs.

Scaffolds to Support Students' Integration of the Dimensions

Researchers have examined how to use verbal (McNeill et al, 2006; Songer et al, 2013) and curricular (cf., Songer, 2006; Songer et al 2009; Songer & Gotwals, 2012) scaffolds to support students' integration of a DCI and SP, but this literature has not included incorporation of the CCC. Here, the curricular unit included scaffolds for the development of SPs and for selecting content to represent. Variations in the curricular prompts meant that students represented different understandings at the same time. Additional research is needed to examine how prompts can be better used to support students in presenting the most thorough representation of their understanding. This approach shows great promise for supporting students' development of metacognition about their changing understandings, and their knowledge of how to use the SPs. This research begins to describe scaffolds to support students' integration of the dimensions, but additional research should focus on the elements that support students' integration, and how those scaffolds should fade over time.

Supporting Teacher Practice

Further research is also needed to examine the moves that teachers make to support integration, particularly in a classroom where the students play a more central role in the development of the knowledge. The present study has described moves that were used in one classroom, but additional research is needed to examine the types of moves that teachers use both in classroom discussion and in supporting individual students to integrate. In addition to the teaching practices described in this research, educative teacher materials should be developed to support instruction for integration by teachers at varying levels and amounts of experience (Ball & Cohen, 1996; Davis & Krajcik, 2005).

This research serves as a starting point for understanding how teaching and learning aligned with the *NGSS* might look in practice. It represents a variety of new understandings about the learning and opportunities to learn that occurred in conjunction with an integrated curricular unit. The next step is to describe a set of design principles to incorporate the CCC into curricular units, and to integrate the three dimensions.

Appendix A – The Full Curricular Unit

Lesson Title: What is topography?

Expected Time: 2 class periods

Guiding Question: How do we represent height on two-dimensional maps?

Materials:

- Computers – Google Maps
- Huron River Watershed Maps
- Clay – One lump per student
- Cutting Wire – One per table

Description of Activities:

**Important for students to understand that water flows downhill, otherwise these lessons aren't going to link very well. **

Using a variety of maps that represent terrain and elevation changes, students explore the variation in how terrain is represented.

With topographic maps as a particular example, students explore what topo lines represent through the construction of a topo map using clay, paper and pencil. Through the examination of topo maps and their examples, students create a list of observations about how topo lines represent changes in terrain.

Synthesis Activities in this Lesson:

Modeling: Draw a model of how topography can be represented in two-dimensions

Explanation: Can a three dimensional feature be represented by a two dimensional model?

Part 1.1

How can height be represented on a two dimensional maps?

1) Look at the maps provided by your teacher. Which maps have elevation (the height of the landscape) represented on the map?

2) How do those maps represent things that have higher elevation?

3) What on the map did you use to determine which areas had higher and lower elevation?

What other ways are there for representing elevation? Topographic maps.

Using the clay provided to you, build a mountain. Try to give the mountain some areas that are steeper, and some areas in which there is a gradual incline.

Using the clay wire, cut the clay into level pieces at regular intervals. For your mountain, this should be approximately every inch of height increase. After each cut, place the top of the mountain back on the piece of paper, and outline the base of remaining mountain.

When you are finished, you have a topo map of your mountain! The lines represent how much horizontal distance it took for your mountain to gain an inch of height.

4) What do the lines look like in the areas where your mountain is steep?

5) What do the lines look like where you mountain had a gradual incline?

Elevation on Maps

Part 1.1

6) Draw a model of how 3-dimensional objects can be represented on a two-dimensional paper.

7) Write a scientific explanation that answers the scientific question:

Can the three-dimensional landscape be represented by a two dimensional model?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Lesson Title: What is a watershed?

Expected Time: 2 class period

Guiding Question: What influences the flow of water in the landscape?

Materials:
- Boyne Area Topo Map
- Dry-Erase Markers (1 per person, 2nd marker one per table)

Description of Activities:

Building on their observations of trends in how topo lines represent the landscape, students look specifically at where water is in relation to the topo lines. Is there consistency in how topo lines look near water? Students explore trends in the way topo lines represent the direction of flow of water.

Using a particular body of water, students identify the areas that are uphill from that body of water. Students draw lines on the map indicating downhill flow of water. Students identify how to locate a boundary where water no longer flows into the body of water.

Synthesis Activities in this Lesson:

Modeling: Draw a model of how water interacts with a watershed.

Explanation: Students use their experience to explain, what makes an area a watershed?

What is a watershed?

1) Using the topographic map provided to you, locate the highest point on the map. What is it?

2) Find a river on your map. What do the topo lines look like adjacent to the river?

3) Which direction (N, S, E, or W) is the river flowing? How can you tell?

4) The topographic lines help indicate how the water is flowing. How do they do this?

Choose a river on the map that you would like to explore. Make sure to tell your teacher which river you chose. Indicate which river you are studying with a green line using a dry erase marker.

Watershed

Part 1.2

5) How do you know where the water would flow?

Using a different dry erase marker, identify the areas of land that are uphill from your river. Draw lines on the map indicating downhill flow.

6) How can you identify where the water in the river comes from?

7) **Draw and label an illustration (a conceptual model)** showing how water moves within a watershed. Make sure to include what influences where the water goes, and what defines the borders of a watershed. This should be your own example, do not draw the same thing that was in class.

8) Write a scientific explanation that answers the scientific question:

What makes an area a watershed?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Lesson Title: How big is a watershed?

Expected Time: 1 or 2 class periods

Guiding Question: What influences the size of a watershed?

Materials:
- National Watershed Map
- State Watershed Map
- Huron River Watershed Map

Description of Activities:

Using their previously developed definition of a watershed, this lesson problematizes the concept. Adding a layer of systems to the concept of watershed, students explore how large and how small a watershed can be. They also explore the concept of nested watersheds, in which the size of the watershed varies depending on what the body of water being examined is.

Synthesis Activities in this Lesson:

Modeling: Draw a model of how water interacts with a watershed.

Explanation: How big is a watershed?

How big is a watershed?

1) How many watersheds are associated with the Huron River?

2) You do not have to locate it, but using your understanding of watersheds, what do you imagine is:

- the largest watershed you can find?
- the smallest watershed?

Size of a Watershed

Part 1.3

3) Draw a model of a watershed. Make sure to include what influences how big the watershed is and what influences where the water goes.

Part 1.3

4) A scientific explanation includes a claim, evidence, and reasoning.

- A "claim" is a complete sentence that answers the scientific question.
- Evidence is the data that helps you answer the scientific question.
- Reasoning tells why your evidence supports your claims. You can use scientific definitions or ideas to explain why you chose the evidence you did.

Write a scientific explanation that answers the scientific question:

How big can a watershed be?

Claim:

Evidence:

Reasoning:

Size of a Watershed

Part 1.3

Size of a Watershed Part
1.3

~~**Lesson Title:** How big is the Huron River watershed? **Expected Time:** 2 or 3 class periods~~

~~**Guiding Questions:** How can we as a group determine the size of a watershed? And for what might this information be used?~~

~~**Materials:**~~

- Topo maps for the Huron River Watershed
- Huron River Watershed Map
- Computers to act as other resources

~~**Description of Activities:**~~

~~In this lesson students try to identify the quantity of land that is the Huron River watershed. Using a variety of maps and materials, students might start by identify which rivers and streams feed into the Huron River, and where headwaters and mouth of the river are. Subsequently students can use whatever resources they have available to identify the land that falls within the Huron River watershed.~~

~~Using the area of land they identified, students should examine what kinds of land-use factors might influence the health of a river. Begin a discussion (to be continued when human impacts are discussed) about wow human land-use influences stream health?~~

~~**Synthesis Activities in this Lesson:**~~

~~Modeling: Draw a model of a watershed. Make sure to include what influences how big the watershed is and what influences where the water goes.~~

~~Explanation: How big is the Huron River watershed?~~

Size of a Watershed

Part 1.3

~~How big is the Huron River watershed?~~

~~Organize an investigation of how big the Huron River watershed is. Some questions to consider include:~~

- ~~What units will you use to describe the size?~~

- ~~What maps would you want to use to answer this question?~~

- ~~How precise do you want your answer to be?~~
    - ~~What might affect your ability to be precise?~~

~~Now that you've looked at maps of the area that feeds into the Huron River: 1) What are some of the man-made features in the Huron River watershed that influence the river's health?~~

Size of a Watershed

Part 1.3

~~3) Write a scientific explanation that answers the scientific question:~~

~~How big is the Huron River watershed?~~

~~** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**~~

~~Claim:~~

~~Evidence:~~

~~Reasoning:~~

Lesson Title: Porosity Lesson

Expected Time: 2 or 3 class periods

Guiding Question: What besides topography influences water flow?

Materials:
- Clipboards and Paper for Outdoor Observation
- Water or a Rainy day to observe water flow
- Plastic Pipes
- Garden Mesh
- Materials of Study

Description of Activities:

Students examine water flow in their schoolyard. What materials impede or enhance surface waterflow? Which materials seem to promote seepage into the ground? Students examine both the destination of surface water and features of the property that influence how the water flows.

Using physical models of surface materials, students examine the differences in the amount of water that can flow through the material. The materials for examination are: Sand, Organic Material, Dirt, Concrete, Paving Material, and Rock.

Using the results from their experiments, students should consider how the ever increasing amount of urban area influences watersheds and the water cycle.

Synthesis Activities in this Lesson:

Modeling: Draw a model of the interaction between the water and the surface materials.

Modeling: Draw a model of how water interacts with the Earth's surface in a watershed.

Explanation: What factors influence the flow of water on the surface of the Earth?

What besides topography influences water flow?

1) Based on your observation of water in the Honey Creek schoolyard: Where does the water at Honey Creek go?

2) Using a map of Honey Creek (see Honey Creek Map), draw some of the features that influence the flow of surface water. Draw things that improved or blocked water flow.

3) Where do you see water flowing? Draw arrows to indicate water movement.

Porosity

Part 1.4

Not all surface materials are the same, as you likely saw in the schoolyard. Some materials encourage water to flow faster and some absorb water.

In order to understand how different materials interact with water, we will create models of different soil types to compare rates of flow through the different types of material. You will need:

- Cylinder to place materials in
- Surface Materials (choose 3)
  - Fine Sand, Course Sand, Mulch, Dirt, Rocks

4) Design an experiment that compares the ability of water to flow through each material.

What question are you trying to answer in your experiment?

What materials do you need to answer that question?

How many times will you do the experiment?

Part 1.4

What procedure will you use to make sure that the different trials are comparable?

5) Which materials are better at holding water within them?

6) Which materials are better at allowing water to move through them?

7) Place the various materials on a continuum of impermeability. To do this, think about: How does each material compare to one another? What are the standards you are using for comparison?

Porosity

Part 1.4

8) Draw a model of what you think is happening with the water and the surface materials. Make sure to include the ways in which the materials are different from one another, making the results different.

9) Urban areas within the United States are continuously expanding, how do you think this impacts watersheds?

Porosity

Part 1.4

10) Draw a model of how water interacts with the Earth's surface in a watershed.

Porosity

Part 1.4

11) Write a scientific explanation that answers the scientific question:

What factors influence the flow of water on the surface of the Earth?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Modeling Watersheds

Part 2.1

Lesson Title: Surface Materials Lesson

Expected Time: 1 class period

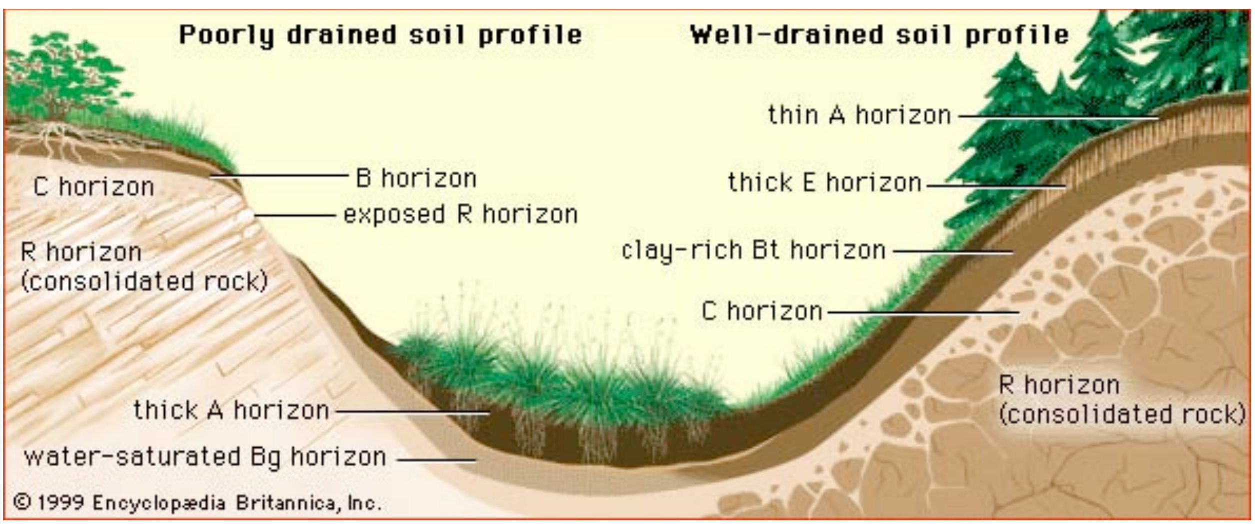
Guiding Question: How are the types of materials that make up different landscapes different?

Materials:

- Data from the porosity lab
- Images from landscapes (Bog/Wetland, Mountain, Alpine, Lake)
- Model Development Sheet

Description of Activities:

This lab serves as both a recap of the lessons learned in the porosity lab, and an introduction to the watershed model development. In this lesson students consider various types of landscapes and how their surface materials are different from one another. Students should use their experience with the Honey Creek surfaces, and their knowledge of landscapes to create descriptions of the landscapes, which can then be considered in the context of the porosity lab to determine which are the most likely surface materials.



Synthesis Activities in this Lesson:

Modeling: Draw a model of the interaction between the water and the surface materials, which represent a particular type of landscape.

How are landscapes different from one another?

1) What are some of the characteristics that make a place a desert?

2) What are some of the characteristics that make a place a wetland?

3) Using the data from the porosity lab. Which materials allowed water to move through quickly?

4) Which materials took longer for the water to move through?

Part 2.1

5) What materials would you expect to be associated with a desert? Why?

6) What materials would you expect to be associated with a wetland? Why?

7) Looking at the map of Boyne Falls. Where are the wetlands located relative to other features on the map?

8) Choose a type of landscape (write the type of landscape at the top of the page), then draw a model of how water interacts with the layers of surface material in that type of landscape.

Lesson Title: Watershed Model Development

Expected Time: 2+ days – 1 to plan, 1+ to develop

Guiding Question: What are the important aspects of a watershed to preserve in a model?

Materials:

- Aquariums or large clear containers – plastic?
- Clay, Dirt, Stones, Sand, Organic Materials & Anything from the Schoolyard

Description of Activities:

Students use natural materials to develop a model of the landscape to observe how topography impacts the potential flow of water.

In the first part, students make a model of their watershed. Students should consider which aspects of a watershed are important to preserve, given the question that they intend to explore. In what ways are the models similar to and different from the real watershed?

Synthesis Activities in this Lesson:

Modeling: Draw a picture of your model.

How can we model a landscape/watershed?

1) Think about a type of landscape that you would be interested in creating. What are some of the characteristics of this landscape that makes it different from other landscapes?

Create a plan for how you will model a portion of a watershed. Here are some questions to consider as you plan your model:

- What layers are important to model?
- How will you model those layers?
- How will you know how much impact the water has on your watershed?

Your watershed model needs to fit the following guidelines. Your model needs to have:

- Bedrock (bricks) on the bottom.
- Distinct layers above the bedrock.
- Organic material (if used) needs to be the top layer(s), both dirt and mulch count as organic materials.
- One end of your landscape should have a mountain. Remember the foundation of mountains are generally rock.
- An area for a lake at one end of the model. Your lake should have the side of the container as one side of the lake.

5) What materials will you need for your model of the watershed?

Part 2.1

6) What is your plan for developing the model of the watershed?

7) Use the space below to draw a picture of your model. How does your model reflect aspects of an actual watershed? Label the elements of your watershed and what they represent.

Lesson Title: Landscape Change

Expected Time: 2+ days

Guiding Question: How does water influence the landscape? **Materials:**

- Watershed model from previous lesson
- Water

Description of Activities:

Students use water to observe the impacts of the material on their watershed over time. Students should make observations of changes over time, and describe the treatment they applied to their watershed.

Synthesis Activities in this Lesson:

Modeling: Draw a conceptual model of how the water interacted with the physical model of the watershed.

Explanation: How does water impact the landscape?

How does water influence the landscape?

1) How do you plan to add water to your model in a way that reflects natural phenomena? Describe your process here.

2) How will you know if the water is impacting the watershed?

Now, add water to your model!

Part 2.2

3) How was what you observed similar to AND different from what you expected?

Similar:

Different:

4) Where did the water have the most impact in the model? How do you know?

5) Where did the water have the least impact in the model? How do you know?

6) How would you expect the impact to change if you added water for a longer period of time?

Part 2.2

7) Draw a conceptual model of how the water interacted with the physical model of the watershed.

8) Write a scientific explanation that answers the scientific question:

How does water impact the landscape?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Human Impact Part
2.3

Lesson Title: Human Impacts on Watersheds

Expected Time: 2 class periods

Guiding Question: How does what we add to the Earth's surface impact ground and surface water?

Materials:
- Model from previous lesson
- Food coloring – red?

Description of Activities:

Students add food coloring to the surface of their models. They then observe where the food coloring goes, and make estimates as to where the majority of the food coloring went. Students should make observations of their model as they add the food coloring, and observations as they add water to their model after adding the food coloring.

Synthesis Activities in this Lesson:
Modeling: Draw a model of how pollution moves in a watershed.

Human Impact

Part 2.3

1) Our intention is to represent human impact on the landscape. Describe three different types of pollution that the addition of food coloring to your model could represent.

2) Where do you expect to see the food coloring after you add “rain” to your model? Why?

Part 2.3

3) In the space below, make observation about where the food coloring is, after you add the food coloring to your model.

4) In the space below, make observations about where the food coloring is in your model after you add water to the model with the food coloring.

Part 2.3

5) Based on your observations of the model and your understanding of watersheds, where and what does the addition of pollutants seem to impact?

Part 2.3

6) Draw a model of how pollutants interact with a watershed.

7) Write a scientific explanation that answers the scientific question:

Which types of water do humans impact in a watershed?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Lesson Title: Systems Synthesis

Expected Time: 2 class periods

Guiding Question: How do systems help us understand the natural world?

Materials:

- Revisit maps and materials from previous lessons

Description of Activities:

In this lesson students learn about the concept of "systems". Using a framework for understanding what makes something a system, students will think of a concept they learned in relation to water that they believe is a system and apply that concept to the framework.

Synthesis Activities in this Lesson:

Explanation: Is a watershed a system?

1) What kinds of experimental questions related to human impact could the concept of a watershed help us to answer? Write down your ideas below.

A system is: an organized group of related objects or components that form a whole. Things that seem to be a subsystem at one scale might be a system itself at another scale.

Systems include:

A Boundary – An artificial division between this system and surrounding systems. A boundary does not have to be between locations, a boundary can be a decision about what you want to include in your system.

Flows Into the System – flows do not have to be liquids, flows could be energy or solid materials… anything that moves into or out of the system.

Flows Out of the System – similar to flows into the system, flows out of the system can be anything that moves out of what you are considering.

Interactions Within the System – interactions can be physical or chemical reactions.

Example system: Photosynthesis

Boundary: Only considering what happens within the plant cells.
Flows Into the System: Water, Sunlight, and Carbon Dioxide
Flows Out of the System: Energy and Oxygen
Interactions Within the System: Water, Sunlight, and Carbon Dioxide react with compounds within the cell to produce sugar and the waste product, Oxygen.

2) Using this framework for understanding systems, think of two examples of systems we've discussed in class. For each system, think about what the boundary might be, what is flowing into and out of the system, and what is interacting in the system.

System Name:

Boundary:

Flows Into the System:

Flows Out of the System:

Interactions Within the System:

System Name:

Boundary:

Flows Into the System:

Flows Out of the System:

Interactions Within the System:

3) Draw a model that shows why a watershed does or does not count as a system.

4) Write a scientific explanation that answers the scientific question:

Is a watershed a system?

** Remember that a scientific explanation is a response that fully explains the evidence and reasoning for a particular answer.**

Claim:

Evidence:

Reasoning:

Appendix B – Background Survey and Pre/Post Test

Name:

Class Section: **Date:**

Student Background Survey

On a scale of 1 to 10, score your responses to the following questions.

A) How much did you enjoy Science class last year?

did not like it! loved it!

1 2 3 4 5 6 7 8 9 10

B) How much do you like using maps?

do not like them! love them!

1 2 3 4 5 6 7 8 9 10

C) How often do you use maps in school?

infrequently frequently

1 2 3 4 5 6 7 8 9 10

D) How often do you use maps outside of school?

infrequently frequently

1 2 3 4 5 6 7 8 9 10

E) What do you use maps for outside of school?

F) When you look at a map do you generally understand what it represents?

almost never almost always

1 2 3 4 5 6 7 8 9 10

G) How much experience do you have with creating models (for example, model airplanes, model cars, Legos, terrariums)?

none I build models weekly.

1 2 3 4 5 6 7 8 9 10

H) What models have you built?

Would you be willing to be interviewed four times to help teachers better understand how students learn about watersheds?

(Conducted by a U of Michigan graduate student.)

YES NO

A conceptual model is a drawing that illustrates your understanding of a particular concept and includes information about how the concept works. For questions 1-3 draw a conceptual model of the concept, and be sure to label the parts of the model.

1. Draw a conceptual model of how water cycles in the Honey Creek schoolyard. Label the parts of your model.
2. Draw a conceptual model of a watershed. Label the parts of your model.
3. Draw a conceptual model showing how water interacts with the watershed. Make sure to include how big the watershed is and what influences where the water goes. Label all parts.
4. How does water (rain) move into the sky?
5. Where does river water go after the river?
6. How do systems help us understand nature?
7. Which of these is the best definition of a watershed?
    a. A building at a water treatment plant
    b. An area of land that drains into a specific body of water
    c. A significant pollution event
    d. Another name for a river or stream
    e. Don't know

A scientific explanation includes a claim, evidence, and reasoning.

- A claim is a complete sentence that answers the scientific question.
- Evidence is the data that helps you answer the scientific question.
- Reasoning tells why your evidence supports your claims. You can use scientific definitions or ideas to explain why you chose the evidence you did.

For questions 7 & 8, write a scientific explanation to answer the scientific question.

8. Write a scientific explanation to answer the question:

    How does water affect the shape of the landscape?

Scientific Explanation:

Claim:

Evidence:

Reasoning:

9. Write a scientific explanation to answer the question:
   Does the Mediterranean Sea have a watershed?

Scientific Explanation:

Claim:

Evidence:

Reasoning:

Appendix C – Interview Protocols (Student and Teacher)

Goals for Student Interviews

- Have the student thoroughly describe their understanding of the concepts at the point and time they are being interviewed. This will provide an opportunity for students to explain how their responses represent an integrated understanding.

Student Interview Protocol

1. Tell me about your conceptual model that you drew.
    a. What is your model illustrating?
    b. Did you consider drawing it in any other way as you were creating it?
2. [Add for 2^{nd} Interview, and Final Interview] How is this model different from earlier models that you drew?
    a. Why is this one different?
3. Tell me about your explanation.
    a. What led you to write this explanation in this way?
    b. Did you consider any other responses for any of the sections?
4. [Add for Final Interview] Can you explain to me, using experiences you had in class, what happens to water after it falls to Earth as rain or snow?

Goals for Teacher Interviews

- Describe the evidence that led to changes or recommendations for future changes in the curriculum.
- Describe the changes made by Jake and Sarah to promote Students' movement along the learning trajectory.
- Describe ways that the curriculum could be revised in a future iteration to promote students' integrated understanding.

Teacher Interview Protocol

1. What were your expectations for students' understanding in today's lesson?
2. Did they get there, or not? Why?
3. What activities (or parts of the lesson) do you feel moved students toward those goals? Or did not move students towards these goals?
4. What from this lesson would you keep the same?
5. If you were going to revise the lesson(s) what revisions would you make at this point?
6. Are there any changes that we can make now for the future lessons?

Final Teacher Interview Protocol

1. What were your expectations for students' understanding from the curriculum as a whole?
2. Did they get there, or not? Why?
3. What activities or lessons do you feel moved students toward these goals? Or did not move students towards these goals?
4. What from the curriculum would you keep the same?
5. If you were going to revise the curriculum what revisions would you make?
6. Are there any concepts that you think students found particularly easy?
7. Are there any concepts that you think students found particularly difficult?

Appendix D – Sample Class Transcript

Complete Transcript from Class on 11/16/12.

Lesson 9, Part 1

Video Recording Transcription by Landmark Associates

Instructor 1: You know there's a lot of [cross talk 00:01], right?

There is higher elevation [cross talk 00:04].

This is your boundary.

Student: Thanks.

Instructor 1: You're welcome.

Student: That helps.

[Shuffling sounds and fading voices 00:14 Ð 01:17]

Instructor 1: Okay, what I want you to have open is your plan which should help you on your homework, have open, which is 2.3.

You had to draw a picture and write a scientific explanation.

In the meantime, in the lab notebook, I want you to copy down these notes in it.

Student: You had to do less than that.

[Shuffling sounds and fading voices 01:36 Ð 01:58]

Instructor 1: Planner open, lab notebook out, jot down the notes on the dry erase board.

I will come by to check in your homework.

Yes, [fading voice 02:11]?

Student: You were in the [fading voice 02:17] in the shape, a marker in it.

[Fading voice 02:21].

Student: Then I just thought of rubbing it on your planer to [fading voice 02:27].

Instructor 1: Mark?

Student: To get what's the [fading voice 02:32].

Instructor 1: Really?

On the sheet.

You're gonna do [fading voice 02:37].

[Shuffling sounds and small group conversations/cross talk 02:39 Ð 03:48]

Instructor 1: I want you to explain to her what happened with the [cross talk 03:52].

Student: First thing you–

Instructor 1:	I don't need that part, once you go [fading voice 03:59].
Student:	Oh my gosh.
	This is–
Student:	What?
Student:	That looked a little [fading voice 04:04].
Instructor 1:	Noah, help her to kind of understand what's on the board.
Student:	We put little drops of food coloring in spots on the landscapes and [cross talk 04:20].
	Then you had to see where they went.
	The green just soaked into the mountain and went down into the [cross talk 04:34].
	Then the red one flowed down a stream into the [fading voice 04:39].
Student:	Jake, I already have this one.
	[Fading voice 04:46].
	[Shuffling sounds and small group conversations/cross talk 04:49 Ð 06:34]
Instructor 1:	All right!
	In your lab notebooks you should be writing down these set of notes right here.
	You have that done?
Student:	No.
Instructor 1:	Do that now, quickly.
Student:	Okay, we just need to finish.
Student:	I forgot to turn my stuff in.
Student:	I thought the ones you [cross talk 05:51] I thought they named the middle school [cross talk 06:53], but then I realized it's alphabetical.
Instructor 1:	Have one person at a table collect the homeworks that are due today.
	Make sure your name is on it and it says "third hour", and you can turn that in.
Student:	Wait.
	Do we [cross talk 07:07]?
Student:	[Cross talk 07:07] have it.
Student:	It's on there.
Student:	Okay, I forgot it [cross talk 07:11].
Student:	I was like [cross talk 07:12].
Instructor 1:	Put the book away.
	[Cross talk 07:14 Ð 07:29]
Instructor 1:	Someone collect it, turn it in.
	Notes.
	[Cross talk 07:32 Ð 07:43]
Student:	It kinda looks like a split or something.
	I think you're saying what is [fading voice 07:49].

Student: We don't have [fading voice 07:52].

Student: No, we don't.

I thought it [fading voice 07:53] for the–

Student: I think it's [cross talk 07:54].

[Cross talk 07:54 Ð 08:02]

Student: We have a test.

Instructor 1: Just write it down and I'll [cross talk 08:05].

Student: Homework is to study for the test.

Student: Take notes on it?

Student: No.

Study your notes for the test.

Student: [Cross talk 08:10] like a little–

Student: Tuesday.

Student: Why is it Tuesday?

Instructor 1: Oh yeah, you get it Tuesday and [cross talk 08:16].

Student: Because we have a test on Tuesday.

He's saying study for the test on Tuesday.

Student: I don't get it, like–

Student: We have a test on Tuesday right now.

Student: I know, but–

Student: He's saying, "Study for the test."

Student: I know, but I'm trying to–

Instructor 1: Just write it down there.

Got it?

Student: Yes, sir.

Instructor 1: Good.

Student: Now you need to write–

Instructor 1: Close planners.

Student: - in your notebook.

Instructor 1: Let me explain.

Student: Do we keep our lab notebooks?

Instructor 1: Yes.

Student: You need to write–

Instructor 1: Keep your lab notebooks.

Close your planner.

You don't need your planner.

Student: Hurry up.

Student: Write in your lab notebook.

Student: I will [fading voice 08:47].

Student: Everybody's already done and Jake is starting.

Student: Okay, I gotta have [cross talk 09:01].

Instructor 1: No.

Student: Oh yeah, that's fine.

Instructor 1: Okay, so let me explain real quick.

On Tuesday next week when you come back from your amazing weekend where you actually looked at your notes, you reviewed all the answers, and you prepared for the test, your responsibility is that you're going to take a test on Tuesday.

This test, if you remember, is very similar to the test that you remember you took at the beginning of this unit where you were like, "I don't know what a watershed is!"

Do you remember taking that test?

Student: Aww, yes.

Student: Yeah.

Student: That test.

Student: [Cross talk 09:46].

Instructor 1: That earlier test where you were like befuddled and did not know how to answer these things, well, we're gonna see how well you've been learning along the way to see if you could answer those questions again, this time around, to be able to take your knowledge, everything that you learned, and be able to apply it to that examination, okay?

Normally, obviously I would give a test, we'd probably do a product about it, and we are gonna do a product about it later on.

Student: Yeah!

Instructor 1: This is kind of part of the scientific process where we're trying to understand what did you know before, or maybe what didn't you know before?

Then now, at the end of the unit, what do you know now?

And seeing what the difference is.

You'll be able to know how you did well in the first one, and then how well did you do on the second one to see how smart you have become now because of our experiences.

Let's try to think positively, how much you did learn in the process.

It's nothing for you to be stressed about.

While you're gonna know how well or maybe how not well [laughter] you did, before and after, that's not my basis for saying like you did pretty well.

Student: [Cross talk 11:00].

Instructor 1: What do you mean?

Student: Like our [fading voice 11:04] or anything.

	Are we gonna [fading voice 11:06]?
Instructor 1:	She's gonna have them, yes, so they will be tracked.
Student:	[Cross talk 11:08] our names [cross talk 11:11]–
Instructor 1:	Of course.
Student:	- [fading voice 11:12]?
Instructor 1:	No, your names won't be on them.
	They don't do that.
	Afterwards they just kinda take the anonymous data and they say, "Well, this percentage of people did really well.
	This percentage of people maybe struggled."
	Your names are never on it.
Student:	Yay!
Instructor 1:	Sammy 11:28.
Student:	Wait.
	Are we done with this unit?
Instructor 1:	No.
Student:	Then why would we get a test?
Instructor 1:	I just explained it.
Student:	I don't get it.
Instructor 1:	This was part of the science experiment that you guys were part of to see how much–
Student:	We usually get one at the beginning and end of the unit.
Instructor 1:	This means we've studied what we know about watersheds and now after this we're gonna understand how that applies to Hawaii.
	You see [cross talk 11:51].
Student:	What?
Student:	[Cross talk 11:52].
Student:	Oh, so we are [cross talk 11:54] unit.
Instructor 1:	Of understanding what watersheds are?
	Yes.
Student:	Just kidding.
	[Cross talk 11:58].
Student:	Okay.
Instructor 1:	Now you're gonna apply it to the next level.
Student:	I'm going to Hawaii.
Student:	I said, "I know we aren't."
Instructor 1:	We're not going to Hawaii, so don't even consider that.
Student:	I don't wanna go to Hawaii.

Student:	[Cross talk 12:07].
Instructor 1:	Well, we're not going physically.
Student:	It means you don't have to.
Instructor 1:	We're going virtually.
Student:	Yeah!
Instructor 1:	On Tuesday, that's when we'll take the test.
	Over the weekend I expect you to look at your lab notebook.
	I expect you to look online at some of the questions.
	All these homework assignments that you glued into your lab notebook, all prior ones, you can take a look at those.
	Because I'm expecting on Tuesday for you to be able to barf out all your knowledge–
Student:	Ew!
Instructor 1:	- about what watersheds are.
Student:	What?
Student:	Okay.
	[Laughter]
Instructor 1:	Never to hear anymore that complaint about, "I don't know what a watershed is!"
	I hear that, I will cry cuz I probably failed as a teacher.
	Got it?
	Get it.
	Good.
Student:	Okay.
	[Cross talk 12:52].
Instructor 1:	What we're gonna do today is we're gonna kinda take a step back from being very detailed about one area of science.
	We've been kind of learning about this whole idea about watersheds, water cycles, topography, ground water, everything like that, about that specific area of science.
	We're gonna take a step back from that and think a little bit more higher level.
	Kinda step back to see, hey, what is science all about?
	How are we using science to kinda study this one specific area, and can we explain that process and the understanding of different subject of science, okay?
	That's what we call understanding systems.
	In science, we look at different systems across different genres of science.
	Kind of like genres of language arts, now we're kind of talking about how do we use science to understand a specific thing and use that kind of skills and process to apply it to a different topic?

For example, if I said we're gonna take the skills and processes of following directions carefully, what kind of characteristics, what kind of qualities do you need in order to follow directions carefully?

If I taught you that skill, what are some things that I would want you to do or practice for it?

Student: [Fading voice 14:17].

Instructor 1: Throw some things out.

Try to be specific.

What would be really essential in order to follow directions well?

Student: Remembering [cross talk 14:28].

Instructor 1: One thing is what?

Student: Remembering the directions.

Instructor 1: Remembering the directions, right?

You need to know what each direction is and remembering and applying it.

Walter 14:36?

Student: Active listening skills.

Instructor 1: Active listening skills, right?

Not just you being like, "Yes, I heard the sound patterns that you made," but you're actually actively kind of engaging.

"Yes, I understand what the first direction is.

I understand what the second direction is."

What else would you need in order to follow directions well?

What kind of qualities or skills?

[Pause]

Student: Listening skills.

Student: Details.

Instructor 1: We already said that.

Obviously–

Student: [Cross talk 15:05]?

Instructor 1: He said, "Active listening."

Student: [Laughter]

[Cross talk 15:09].

Instructor 1: Frazier 15:09.

Student: Like note-taking.

Instructor 1: Note-taking, right?

If you don't remember them, at least writing the skills down, or the steps down.

That might be essential.

Sammy.

Student: Asking questions if you don't understand.

Instructor 1: Yes.

If you don't understand it, asking questions [cross talk 15:23].

Those are all kind of things.

Would order matter in following directions?

Student: We're gonna–yeah.

Instructor 1: If you don't follow the order, the way that you follow directions will result in a bad situation, right?

For example, if you took making a pizza.

If I told you the directions on how to make the pizza, but you said, "You know what?

First, second, third, fourth, fifth, that doesn't really matter.

I'm just gonna follow each direction carefully, but I'm not gonna put it in order."

Are you gonna end up with a good pizza afterwards?

Student: No.

Student: [Cross talk 15:54].

Instructor 1: Excuse me.

Do we kinda get the idea that if you understand the skills and processes of following directions carefully, you can apply it to something else.

Making a pizza, right?

Learning how to ride a bike.

If you follow directions carefully you can apply it to many different areas or subjects, right?

Student: Yeah.

Instructor 1: Do you kinda understand?

That's kind of like the–if you take a step back, that's the basic skills that you need to understand, how to follow directions.

You can apply it to different areas on there, right?

What we're gonna do today is we're gonna try to understand the basic skill of what systems are in science.

How do I identify these?

How do we use these in science to understand specific categories?

I'm gonna teach you how to look at systems by using a specific example.

In the end, I want you to use those basic skills of what a system is to apply it to watersheds.

Another example.

Student: To what?

Instructor 1: To watersheds.

Does that make sense?

We're gonna use another example to kinda understand what it's all about, that scientific skill process.

Then we're gonna apply it to watersheds later on.

Student: Is we gonna–

Instructor 1: Gotcha?

Student: Yeah.

Student: Mm-hmm.

Instructor 1: Okay, so in your lab notebooks, what I want you to do is we're gonna use the system of a–

Student: [Fading voice 17:27].

Instructor 1: In your lab notebooks I want you to write this down as our example.

[Pause]

Student: This is [cross talk 17:39] definition.

Instructor 1: A plant cell.

Student: I used the [fading voice 17:41].

Instructor 1: I'm glad that you're excited, but I don't know why you're excited already.

Student: Cuz it just [fading voice 17:49].

Student: Yeah.

Instructor 1: This is true.

Student: Something–

Instructor 1: True, though, [fading voice 17:52].

Student: You know it's [cross talk 17:55].

Instructor 1: Let's understand what a system is.

In general, a system is an organized group of related objects or components that form a whole.

All these different pieces and parts to it that kind of form this whole idea or physical thing that we're gonna start to understand.

That system that we're gonna use as an example in the first one is a plant cell, okay?

If we take a look at it, take a look at my wonderful drawing here–

Student: Oh, that's a beautiful drawing.

Instructor 1: Oops.

Okay.

Student: [Laughter]

What?

Student: [Cross talk 18:32] plant [cross talk 18:33].

Student: Exactly.

Student: Oh, I see.

Student: Okay!

Instructor 1: Okay?

Sorry.
Maybe my drawing's not as good as yours.

Student: [Laughter]

Instructor 1: If we understand this plant, we draw this into your lab notebook so we can use this example to understand the process or skill of a system.
If we look at the basic building block of life for a plant, or even the basic building block of you as human beings, what is the smallest living unit that you guys are made up of?

Student: [Cross talk 19:12].

Instructor 1: Remember, it can't be like an element–

Student: Cells.

Instructor 1: - because that's not really living.
What is the basic building block of living thing that makes up you–

Student: Water?

Instructor 1: - it makes up a plant, and makes up all living things?

Student: Water?

Student: Cells.

Instructor 1: Cells, right?
A plant cell is gonna be our system.
If we kinda draw this [student coughs 19:34] in the leaf a really [student coughs 19:37] thing–

Student: Quiet, please.
Thank you.

Instructor 1: - is this thing called a plant cell.
Right?
Plants are made up of a tremendous amount of plant cells.
You human beings are made up of cells all the time.
[Pause]
Make sense?
[Pause]
In a system there are these organized group of related objects or components that form a whole.
There is definitely something that identifies a boundary.
In every system that there is in science, whether it's a plant cell, whether it's a watershed, whether it's any other different system that we're studying, there's always boundaries.
Well, if we think about the word boundary, how would you explain that?
Where have you heard the word boundary used before?
How does it actually mean?
Catherine.

Student: Kinda like where you have to stop and–or like something like that.

Instructor 1: Yep.

It kinda defines the limit, right, of–for example, if we're playing a game, a boundary is defined by, hey, that's where you cannot go either past, right?

A boundary might define the way that you have to actually move.

That's kind of like the limit or the area that you can't go anywhere around.

In a plant cell, much like a game, is there a boundary for that system?

Student: Yes.

Student: Yes.

Instructor 1: Is there an area that kinda limits where you're actually talking about?

Student: Yeah.

Instructor 1: Right?

That is called, I don't know if you guys know this, depends on how well you know plants, plant cells.

You know what that boundary is called?

Student: Is it [student coughs 21:28]?

Instructor 1: I'm really [student coughs 21:30].

Student: I know this.

This [cross talk 21:33].

Instructor 1: This should be taught in all the earlier grades.

Student: Is it like a cell edge?

Student: No–

Instructor 1: Cell edge, kind of?

Student: Cell wall.

Instructor 1: Cell wall.

Student: Wall.

Instructor 1: Beautiful.

Student: I knew that.

Instructor 1: In your picture, I want you to write the words cell wall.

In middle school we're gonna learn about plants at the end of this year, but I was hoping that either in four-five or three-four–no, four-five or two-three or K-1, someone touched upon this idea of a cell wall.

Student: No.

Instructor 1: No?

Awesome.

Student: I think we did.

In four-five when we did our [cross talk 22:08].

Instructor 1: You should have talked about this.

Student: I didn't do that [cross talk 22:11].

Instructor 1: If you don't have a cell wall in a plant cell, your plant will not stay vertical.

The leaves will not go out like this.

It'll just wither and go like this, and your plant will go like this.

Cuz the cell wall's the outer boundary for this system of a plant cell.

That defines one cell versus another plant cell.

Right?

In our definition here, if you want to write down, the boundary for a plant cell is what?

Cell wall.

[Pause]

Student: [Coughs]

Instructor 1: You okay?

Student: I'm okay.

Instructor 1: You need a drink of water?

Student: I'm okay.

Student: [Cross talk 22:59].

Instructor 1: Cell wall is a boundary, right?

Maybe let's try to think about this.

In a watershed, if we use another example, is there a boundary of a watershed?

Student: Yeah.

Instructor 1: What would define the outer limits or edge or the things that we're talking about for a watershed?

There is, right?

Student: [Cross talk 23:22].

Instructor 1: We'll kind of look at that a little bit while, but let's try to think about that term.

Student: [Cross talk 23:29].

Instructor 1: We'll talk about [fading voice 23:35].

No, I can't.

Student: No, so–

Instructor 1: All right, let's move onward.

In a plant cell in this system, the next criteria that we're looking for is what flows into it?

In a system, there are things that always flow into it.

There's always things that flow out of it.

That's what is considered a system.

Things flow in and flow out of it.

For a cell of a plant, or even a plant, in general, what are some of the things that are required for the plant?

What has to go into it in order for that cell, that system, to work well?
I know you all have worked on [cross talk 24:15].
What needs to go into a plant in order for that plant to work well?

Student: Sunlight.

Instructor 1: Lizzie, what's one thing?

Student: Water.

Instructor 1: Yes, so what goes into it is definitely water.
You don't feed water to a plant, that system will not work anymore.
It'll just get destroyed.
Water's one thing.
What else?

Student: Sunlight.

Instructor 1: Sammy.

Student: Vitamin D or sunlight.

Instructor 1: [Laughter]
Vitamin D.
We're actually–sorry.
I want to draw this to make it different from an actual physical thing.
Sunlight is [pause]–sorry, you should draw it like this.
[Pause]
This is sunlight.
The waves kind of represent energy.
That's why it's different from like just a straight arrow, cuz a straight arrow kinda represents physical things or chemical [fading voice 25:13].
This is energy.
It goes into plant cell.
It needs water, it needs sunlight.
It also needs what?
David?

Student: Sugar?

Instructor 1: You feed a plant sugar?

Student: No.

Student: [Fading voice 25:31].

Instructor 1: Oh, it makes sugar, right?

Student: Oh.

Instructor 1: That's the flow out.
Let's kind of draw this out.

	Sugar.
	[Pause] That's one out thing, but we're still missing one more component that comes into a plant.
	Austin.
Student:	Dirt.
Student:	Dirt.
	[Laughter]
Student:	Soil.
Instructor 1:	Dirt is required because that's what we plant it in.
Student:	Soil.
Student:	Soil.
Instructor 1:	It doesn't take in the actual dirt, itself.
	Aleigha 26:01.
Student:	Carbon dioxide.
Instructor 1:	Carbon dioxide, right?
	That's what plants breathe in, CO2.
	That's what we're talkin' about rain forest being cut down, all these green spaces being cut down.
	It's because–it's really dangerous for us because it doesn't take carbon dioxide out of the atmosphere.
	We can't breathe just carbon dioxide.
	Plants breathe it for us because [pause] it produces sugar.
	What else flows out?
	Now we're kinda moving to the next level.
	What flows out of the system?
	Lucy.
Student:	Oxygen.
Instructor 1:	Oxygen, right?
Student:	Sure.
Instructor 1:	Plants breathe out O2.
Student:	[Cross talk 26:43].
Instructor 1:	It's like the opposite of us.
	We breathe in oxygen, we produce carbon dioxide.
	Plants breathe in carbon dioxide, they produce oxygen.
	Wait, that's weird.
	That's like a system in itself, right?
Student:	Yeah.
Instructor 1:	Things flow into this world system–
Student:	Oh–

Student: We breathe [cross talk 27:01].

Instructor 1: - and then things flow out of it.

Kind of like, whoa.

Student: We breathe oxygen, breathe out carbon dioxide.

Instructor 1: We're systems in systems.

Student: [Fading voice 27:09].

Instructor 1: If we kinda write down our example what flows into it, you said H2O, we said sunlight, I think Marie said carbon dioxide.

What flows out?

I'll show you.

Student: [Cross talk 27:23].

Instructor 1: And oxygen.

Do these make sense, like what flows into a system, what flows out of it?

Student: Yeah.

Instructor 1: These things can be physical, like we're talking about water and carbon dioxide.

It can be something that's not very [student coughs 27:43].

Let's say, for example, you consider your family a system.

What needs to flow into your family?

Student: Love.

Student: [Cross talk 27:54].

Instructor 1: Love, caring.

Student: No.

No.

Instructor 1: No?

Student: Money.

Instructor 1: Food has to flow into your family, as well.

Student: Money.

Instructor 1: That's a physical thing, but if you don't have love, you don't really have family.

The family starts to break down.

Student: [Cross talk 28:08] children hate the father.

Student: [Cross talk 28:08] related anymore.

Instructor 1: Rawr, rawr, rawr, rawr.

Student: [Laughter]

Instructor 1: Anyways, so these things flow in, these things flow out, but how do we describe this last part?

What happens within a system to kinda change this water, sunlight, and carbon dioxide into sugar and oxygen?

Cuz when we flow out, we don't see water flowing out.

We don't see sunlight flowing out.
We don't see carbon dioxide flowing out.

Student: [Cross talk 28:30].

Instructor 1: What happens inside?
What's the interaction?

Student: Photosynthesis.

Instructor 1: Photosynthesis, right?
Alex said photosynthesis.
We're gonna write that in here.

Student: Photosynthesis.
Sorry.

Instructor 1: That's the interaction: photosynthesis.

Student: [Cross talk 28:47].

Instructor 1: Fortunately for us, when we understand the plant cell, photosynthesis is a chemical reaction.
Things come in, they transform, they rearrange their molecules to form something else at the end.
That's kinda what defines a chemical reaction.
You have to rearrange the molecules to form new products.
[Pause]
It could be a chemical reaction, it could be just [student coughs 29:22].
[Pause]

Student: [Cross talk 29:27].

Instructor 1: It doesn't necessarily have to change.
It could be physical or chemical.

Student: [Cross talk 29:30] if you don't [fading voice 29:34].

Student: What?

Student: [Fading voice 29:38].

Instructor 1: For example, if we used the pizza analogy, if I put onto the pizza, which is kind of considered my system, if I put cheese on top of it, right, that's an in.
The interaction that happens with this pizza is what?

Student: Melts.

Student: [Cross talk 29:58].

Instructor 1: It has to add heat to it, right, so that it bakes.
You're kinda changing the dynamics of it.
Then what flows out of it?
Does cheese turn into something else at all?
No, right?

Student: Yeah.

Instructor 1: It comes in, it changes, maybe like its physical matter, it turns more liquidy, right, as opposed to solid.

What comes out of it is still cheese, right?

Student: That's [cross talk 30:21].

Instructor 1: That interaction, it doesn't have to be a chemical one; it can just be a rearranging of physical things to come out as something else.

Eventually, later on, your pizza will turn hard.

The cheese will turn hard.

It's not so liquidy anymore, but it didn't change chemically.

Things could happen where it's just something happens to it.

Instructor 1: What we're gonna do is we're gonna take a look at how now does this apply to another example?

Let's take systems, this idea of understanding how things work, and let's apply it to our watershed example.

You did a great job with the plants and understanding the system part of it, but how can we look at watersheds as our system, okay?

The paper that I just handed out to you kinda gives you a definition of each one of these.

Boundaries, flows in, flows out.

Let's now apply this maybe to a watershed.

We'll try to walk through it step-by-step, but I'm not gonna give you the answers.

I want you to write down what you think it is in your sheet of paper at the bottom.

You notice where it says system name in bold letters?

Student: Yeah.

Student: Yeah.

Instructor 1: Can you write down watershed as our system?

We're gonna look at watersheds now, see [pause] if this can apply in a system.

Can a watershed be a system?

Student: I think [fading voice 32:10].

Instructor 1: Let's look at examples of watershed.

One example we used was like a physical model.

We used this thing called a map, right?

This is not the actual watershed, itself.

This is kind of a representation of it.

Student: [Fading voice 32:26], let me see this.

[Cross talk 32:27].

Instructor 1:	From this map can we get some information about whether it has boundaries, whether things flow into it, whether things flow out of it, and then also are there any interactions that happen for a watershed?
	Or, if this doesn't work for you, maybe we could use another model, like this.
Student:	[Laughter]
Student:	Why is it green?
Instructor 1:	Instead of a flat piece of paper–
Student:	[Cross talk 32:50].
Instructor 1:	- representing a model, what about a physical model?
Student:	For, okay.
Instructor 1:	This watershed that you guys created over the past two weeks, right?
	Let's use this as our example if that doesn't work for you.
	First, what I want you to do on your piece of paper right under the system name is, are there things about this watershed that could be defined as a boundary?
	[Pause]
	What I want you to do on that piece of paper, right next to the word boundary, is try to describe for me in words what are the boundaries of a watershed?
	Can you identify what a boundary would be for that watershed?
	Write it down on that piece of paper.
Student:	[Fading voice 33:30], you're focusing on this.
	Here, do this.
	[Pause 33:32 Ð 33:42]
Instructor 1:	You look at this map, what would define the boundaries of that watershed?
	[Pause]
	How would you know one watershed from another?
	[Pause 33:53 Ð 34:19]
Instructor 1:	Maybe even for a physical model, what would define the boundaries of the watershed?
Student:	[Fading voice 34:26].
Instructor 1:	All right.
	How would you know, for example, in a watershed we know that things flow into it, things flow out of it.
Student:	But like [fading voice 34:37].
Student:	[Cross talk 34:41].
Instructor 1:	How would you know from one watershed from another?
	For example, like Karen, you have a watershed right there.
	That's a system, but what are the boundaries for that system?
	How do you know where that system begins, how do you know where that system ends?

Student: I have to [cross talk 34:56].

Instructor 1: What are the limits to it?

Next thing.

Let's go down the list.

In the watershed, if it is a system, how do you know what flows into it?

What are the things that flow into your watershed?

Can you identify what those things are?

[Pause]

What would flow into the watershed?

[Pause] What would flow into the watershed, the system?

Student: It can't be physical or what?

Instructor 1: It can be something physical, it can be something not a physical, too.

Student: Would–

Instructor 1: Example, we've used that family analogy, if family was a system.

Things that flow into it is love.

Student: Ohhh!

Student: [Fading voice 35:56].

Instructor 1: Huh?

Student: [Fading voice 36:01] flow out of the system.

Instructor 1: Things flow into it, so with the plant cell, would it be able to survive like every single one of those components?

Student: Mm-hmm.

Instructor 1: Right?

Sunlight, carbon dioxide, [pause] what else did I say?

Energies.

Student: Finish.

Instructor 1: Animal, as well.

It might be in the landscape–

Student: Just [cross talk 36:27].

Instructor 1: - of a watershed.

Does the watershed need animals in order to survive?

Student: [Cross talk 36:35].

Instructor 1: This one might be really obvious.

What flows into a system of a watershed?

Student: Water.

Student: [Cross talk 36:39].

Instructor 1: Water, right?

That's pretty obvious.

Student: [Cross talk 36:40] thing that fall into it.

Instructor 1: Things that fall into it.

Then here, the next one, what flows out of a watershed?

I know you're gonna kind of kinda think about this very plain and simple, but what I want you to do is consider what we did this past week.

What flows out of a watershed?

Student: What?

Instructor 1: Write it down in your section there.

What could flow out of a watershed?

Instructor 1: It's not just water.

You experienced it, right?

Did you get pure water at the end of it?

No, so what flows out of a watershed?

Start writing those down?

What else do you see flow out of your watershed?

Did you get pure water?

Student: No.

Instructor 1: No.

There's things that flow out it.

Student: Can we write muddy water?

Instructor 1: Mud?

There's water.

What else?

Student: [Cross talk 37:35].

Student: That's what I said.

Instructor 1: No.

Muddy water is not a [laughter] [fading voice 37:37].

Student: How are you gonna explain that?

Instructor 1: What's inside the water?

Student: Just like sediments?

Instructor 1: [Cross talk 37:45]?

What else?

Student: [Fading voice 37:48].

Instructor 1: That's how you identified the components.

Student: [Cross talk 37:51].

Instructor 1: Lastly, this one: interactions within the system.

In your watershed, was there something that happened to whatever flows in, did it go through anything, any kind of experiences before it went out?

Student: Like what [cross talk 38:08]?

Instructor 1: It could be a chemical change, it could be a physical change, physical meaning that it just might have moved around, right?

Did your inputs go through any kind of experience before it went out of your system?

Student: I don't know this one.

Student: [Fading voice 38:23].

Instructor 1: Okay, we're gonna get back to this on Tuesday.

What I want you to do is to take that sheet, put it in your binder, and we'll talk about it again.

Remember, review your watersheds.

Hopefully, we'll rock [cross talk 38:39].

Student: Do we need to take the sheet [fading voice 38:42]?

Instructor 1: No.

It's just kind of stuff [fading voice 38:44].

[Pause]

Student: Is this gonna be on the [cross talk 38:54]?

Instructor 1: Well–

[Shuffling sounds and cross talk 38:56 Ð 39:58]

Student: Can I have one?

Student: No, you have five.

Okay, people, just one rule.

[Cross talk 40:03].

[Cross talk 40:03 Ð 40:25]

Instructor 1: Seats.

Seats.

[Cross talk 40:27 Ð 40:32]

Instructor 1: Put the squishy stuff away.

I don't wanna see it.

Student: [Cross talk 40:35].

Instructor 1: Actually am repulsed to find [cross talk 40:37].

[Cross talk 40:37 Ð 40:46]

Instructor 1: Actually, I can't clean up with this [cross talk 40:47].

Student: Well, it was raining five minutes [cross talk 40:49].

[Cross talk 40:49 Ð 41:27]

Appendix E – Table of Codes and Their Definitions

Student Work Coding Rubric

	+	-	0
DCI			
Elevation	Shows/states that elevation divides bodies of water AND water flows downhill	Shows/states that water flows downhill	Does not show/state cause or mechanism
Infiltration	Shows/states water infiltrates into the ground with discussion of materials of mechanism	Shows/states water infiltrating into the ground without discussion of mechanism or material	Does not show/state cause or mechanism
Water Cycle	Shows/states water cycling AND show the sun as the mechanism	Shows/states water cycling without the sun as a mechanism	Does not show/state movement.
CCC			
Borders	Shows/states that elevation serves as a border to watersheds	Shows/states that watersheds have a border	Does not include a border or reference to a border
Nested Systems	Shows/states that watersheds are nested within watersheds	Shows/states that watersheds are nested within watersheds	Does not include reference to nested systems
SP			
Model	The model includes diagram with mechanism and labels.	(The model includes a diagram with movement AND explanatory text that tells instead of shows) OR (a diagram without sufficient text).	The model does not include movement.
Explanation	The explanation includes claim evidence and reasoning that correspond to the scientific question.	The explanation includes claim AND (evidence that correspond to the scientific question OR reasoning that relates to the scientific question).	The explanation includes only a claim or no information related to the scientific question.
	3	**2**	**0**
Integration	Models that include a + or – for DCI AND CCC AND SP	Models that include a + or a – for DCI OR CCC (AND SP)	Models that include NO + or – scores

Class Discussion Coding Rubric – Full Set of Applied Codes

Code	Definition	Example
SET	Mark sets of statements that go together. Can a set of statements be integrated?	T: So then I want you to answer this question, which way would you draw the contour lines that area really close together? Which side would you draw these lines? This side or this side.

Code	Definition	Example
A	Any dialogue focused around the regular practice of teaching and the management of students. An admin task may be distributing materials, focusing students' attention or taking attendance for example. Heading a notes page is also an example of an administrative task since science topics are not being discussed, just words mentioned. Calling on individual students to participate. Providing positive feedback.	T: Alrighty, let's gather back together.
S	Any dialogue focused on science content related to the Disciplinary Core Idea of the unit.	T: How did you tell elevation changes from one side to the other?
N	Any dialogue focused on science content not related to the Disciplinary Core Idea of the unit.	I: This girl is contemplating the fact that while some of us have clean water to drink, about a billion people in this world do not have decent water to drink.
U	Unrelated to science class.	Student: do I have something on my mouth?
Y	Yes or No response.	Student: Yeah.

C	Clarifying what was heard by asking a student to repeat, or clarifying whether students remember material from a previous class.	T: You guys remember that?
I	Interjection – any noise or statement interjected but absent content for example: oooh, ahhh, interesting, oh darn! These are neither confirming nor disconfirming in nature.	Student: Woah.

Working definitions for second round codes all are subcodes of SCIENCE (from the 3rd round):

Code	Definition	Example
DCI	Any dialogue in which the movement of water is mentioned, either in the atmosphere, hydrosphere, or geosphere. The movement of water could be the flow of water, water falling, or references to which direction the water would flow.	T: The rain's going to fall even faster and it's probably going to go down the steeper slope.
SP – D	Dialogue that discusses maps, charts, graphs or tables, the interpretation of data to provide evidence, and the similarities or differences between observations. ALSO the limitations of the data analysis, measurement error or improving analysis through revising the methods for example using multiple trials.	T: First question should ask you to identify where the highest elevation point is on the map.
SP – I	Dialogue used to plan or conduct an investigation. Including describing what tools are needed, how measurements will be recorded, and the amount of evidence needed. Evaluating and revising experimental design. Evaluating the accuracy of the data collection methods.	[No examples yet.]
SP – E	Building an explanation or prediction of a phenomena using qualitative or quantitative relationships between variables. Constructing explanations using models or representations. Building an explanation based on the assumption that the laws of nature are constant. Apply scientific ideas, principles and/or evidence to construct, revise, and or use an explanation. Apply scientific reasoning to show why the data or evidence is adequate for the explanation. Focusing on written and drawn explanations.	T: How do you know where water flows? T: It should be labeled, it should be explained, it should be drawn.
SP – M	Develop or modify a model based on evidence to match what happens if a variable or component of a system is changed. Use and or develop models of simple systems. Develop and/or revise models to show the relationships among variables including the effects of unobservable variables on observable phenomena. Use models to predict and/or describe phenomena. Develop a model to describe unobservable mechanisms.	T: In other words, they could take this mountain [picks up the clay model of a mountain] and instead of each slice being like one hundred feet like I told you when we did it, I could slice this mountain every one foot.

	Use a model to generate data.	
SP – A	Construct use and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. Discussion around a point that has not already been accepted as true by the members. In these conversations the teacher should not be explaining the accepted answer, but there should be dialogue around how the point is understood. (Bricker & Bell, 2008)	T: 5, how many people agree with [student] right here, five?
CCC	Any dialogue in which a component of a system is raised, including: nested systems, system boundaries, inputs, outputs, or system processes.	[No examples yet.]

Dimension	**Code**	**Sub-dimension**	**Description**	**Example**
DCI-W	L	Water on **Land**	Specifies the movement of water without saying in water bodies. Can refer to an “area of land” where water falls, or falling water without a clear destination. Can also refer to locations within a watershed for context.	“if rain happened to fall on top of this… can I use this map to figure out where water would go?”
	U	Water **Underground**	References to ground water or the infiltration of water into layers of soil. Includes discussion of different surface materials, and rates of infiltration.	
	W	Water in **Water**	Water moving in streams, rivers, creeks, oceans or	“Or for example, if there's a stream, would you be able

		Bodies	other bodies of water. The water does not necessarily have to be moving.	to tell which direction it's going to flow?”
	A	Water in **Atmosphere**	Water in clouds, evaporation, condensation, in the sky, including rain fall. Also includes references to the “water cycle”.	T: The rain's going to fall even faster and it's probably going to go down the steeper slope.
	S	Driven by **Sunlight**	The cause of water evaporation.	[No examples yet.]
	G	Driven by **Gravity**	Water goes down, moves faster on steeper slopes, slower on gradual slopes. Things move down as driven by gravity.	“going to go down the steeper slope with maybe more velocity right? As opposed to a slow gentle.”
	E	**Elevation**	Reference to the elevation or height of a location or how elevation influences water flow. Also includes how big a watershed can be and references to the boundary of a watershed.	“And on this board how did we tell one place was higher than the other in terms of elevation?”
DCI-HI	HI	**Human Impacts**	Societal activities have had major effects on land, ocean, and atmosphere.	
	P	**Protect**	Societal activities can also help protect Earth’s resources and environments.	
CCC	N	Nested Systems	Reference to systems within systems, or the nesting of systems.	[No examples yet.]
	I	Inputs	Explicit discussion of the inputs to a system.	[No examples yet.]
	P	Processes	Explicit discussion of the processes in a system.	[No examples yet.]
	O	Outputs	Explicit discussion of the outputs of a system.	[No examples yet.]

	B	Boundary	Reference to a system boundary. How it is determined.	[No examples yet.]

SP	**DG**	**Data Analysis – Graphical Displays**	**Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships, references to topography.**	**"So in that kind of map they used colors they used kind of pictures to represent"** **"T: X marks the spot represents what elevation?"**
	DE	Data Analysis – Provide Evidence	Analyze and interpret data to provide evidence for phenomena. References to topography related to the flow of water.	T: If I took a look at this map would I be able to tell, if rain happened to fall on top of this map, can I use this map to figure out where water would go?
	DL	Data Analysis – Analysis Limitations	**Consider limitations of data analysis** (e.g., measurement error) and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).	Student: Well it is anywhere from twenty to thirty feet because since there's no contour line um it could be anywhere between.
	DS	Data Analysis – Similarities and Differences	Analyze and interpret data to determine similarities and differences in findings.	T: Color here doesn't represent elevation, right?
	IP	Investigations – Plan	Planning an investigation individually and collaboratively, and in the design identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.	[No examples yet.]
	IC	Investigations –	Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to	[No examples yet.]

	Conduct	serve as the basis for evidence that meet the goals of the investigation.	
IE	Investigations – Evaluate	Evaluate the accuracy of various methods for collecting data.	[No examples yet.]
ID	Investigations – Collect Data	Collect data to produce data to serve as the basis for evidence to answer scientific questions or to test design solutions under a range of conditions.	[No examples yet.]
ED	Construct Explanations – using relationships to predict or describe	Construct an explanation that includes qualitative or quantitative relationships between variables that predicts and/or describes phenomena.	Student [reading the worksheet question]: the topographic lines help indicate how the water is flowing.

EM	**Construct Explanations – using models**	**Construct an explanation using models or representations. Includes describing model drawings or the process of drawing a model.**	**So you'd have to explain what the map is showing us, the geography of it, the landscape, and then show us in terms of direction, arrows, where water is flowing and how you know which way it goes.**
EE	Construct Explanations – Using evidence	Construct a scientific explanation based on valid and reliable evidence obtained from sources (including students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	T: Yeah on the back of this drawing it says, like the claim evidence and reasoning.
EA	Construct Explanations –	Apply scientific ideas, principles, and/or evidence to construct, revise, and/or use an explanation for real-	T: Basically after this activity what we want you to do

	Apply an explanation	world phenomena, examples, or events.	is we want you to kind of think about a real example.
ER	Construct Explanations – Apply Reasoning	Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.	T: You don't see another circle to represent 30 feet so that's gotta be the answer between 20.0001 to 29.9999999.
ME	Model – Evaluate	**Evaluate limitations** of a model for a proposed object or tool.	[No examples yet.]
MC	Model – Changing Variables	Develop or modify a model – based on evidence – to match **what happens if a variable or component of a system is changed.**	Student: What we did was we took the wire and cut straight through putting them into smaller groups areas, and then we trace out the outline.
MS	Model – Simple Systems	Use and/or develop a model of **simple systems** with uncertain and less predictable factors.	[No examples yet.]
MU	Model – Unobservable Variable Change	Develop and/or revise a model to **show the relationships among variables** including those that are not observable but predict observable phenomena.	[No examples yet.]
MP	Model – Prediction	Develop and/or use a model to **predict** and/or describe phenomena.	[No examples yet.]
MD	Model – Describe	Develop a model to **describe unobservable mechanisms.**	[No examples yet.]
MG	Model – Generate Data	Develop and/or use a model to **generate data to test ideas** about phenomena in natural or designed systems, including those representing inputs and	[No examples yet.]

		outputs and those at unobservable scales.	
AE	**Argument – Explanation**	**Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. Includes giving an example of a phenomena and reviewing parts to make sure new examples fit the explanation.**	**Color here doesn't represent elevation, right? Cause some of you are looking at it and you're like, "It has nice little pictures of marsh. I guess that's really tall." And you're like no that probably didn't make sense. So green doesn't represent height.**

Appendix F – Case Study Students' Triangulated Student Work Data

Student # 301	**Model**				**Model Interview**				**Explanation**				**Explanation Interview**			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Type**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**
Pre-Test	NOT	0	–	0					NOT	0	0	0				
Pre-Test	NOT	0	0	0												
Lesson 2 (2)									2D	–	–	0				
Lesson 3 (2)																
Lesson 4																
Lesson 4																
Lesson 4 (3)																
Lesson 5	3D	–	–	–												
Post-Test (4)	2D	0	–	–					2D	–	–	0				
Post-Test (4)	2D	–	+	–	2D	–	+	0								

Student # 302	**Model**				**Model Interview**				**Explanation**				**Explanation Interview**			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Type**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**

Pre-Test	NOT	0	–	0					NOT	0	+	0				
Pre-Test	NOT	0	0	0												
Lesson 2 (2)	2D	–	+	0	3D	–	+	–	2D	–	+	0				
Lesson 3 (2)	3D	+	+	+	3D	+	+	+					2D	0	+	–
Lesson 4	2D	+	–	0												
Lesson 4	2D	–	–	0												
Lesson 4 (3)					2D	+	+	0	2D	+	+	0	2D	+	+	0
Lesson 5	2D	+	+	0												
Post-Test (4)	3D	+	–	+					2D	+	+	0				
Post-Test (4)	2D	+	–	0	2D	–	+	0								

Student # 304	**Model**				**Model Interview**				**Explanation**				**Explanation Interview**			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Type**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**
Pre-Test	NOT	0	–	0					2D	–	–	0				
Pre-Test	NOT	0	–	0												
Lesson 2 (2)									NOT	0	–	0				
Lesson 3 (2)	3D	–	–	–												
Lesson 4	2D	+	+	0												
Lesson 4	3D	–	+	–												
Lesson 4 (3)	2D	+	+	0					2D	+	–	0				

Lesson 5	2D	+	–	0												
Post-Test (4)	2D	–	–	0					NOT	0	+	0				
Post-Test (4)	3D	–	+	–	2D	+	+	0								

Student # 306	**Model**				**Model Interview**				**Explanation**				**Explanation Interview**			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Type**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**
Pre-Test	2D	–	–	0					2D	–	+	0				
Pre-Test	2D	–	–	0												
Lesson 2 (2)	2D	–	+	0	2D	–	+	0	2D	–	+	0				
Lesson 3 (2)	3D	–	–	–	2D	–	+	0	NOT	0	–	0	NOT	0	+	0
Lesson 4	2D	–	–	0												
Lesson 4	NOT	–	0	0												
Lesson 4 (3)	2D	+	–	0	3D	+	+	0	2D	+	–	0	NOT	0	+	0
Lesson 5	NOT	–	0	0												
Post-Test (4)	NOT	0	–	0					NOT	0	–	0				
Post-Test (4)	NOT	0	–	0	NOT	0	+	0								

Student # 307	**Model**	**Model Interview**	**Explanation**	**Explanation Interview**

Assignment #	Integration				Integration				Integration				Integration			
	Type	Dimensions			Type	Dimensions			Type	Dimensions			Type	Dimensions		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	2D	–	–	0					2D	–	+	0				
Pre-Test	2D	–	–	0												
Lesson 2 (2)	3D	+	–	+	3D	–	+	–	2D	–	–	0				
Lesson 3 (2)	3D	–	–	–	3D	–	+	–	NOT	0	–	0	3D	+	+	+
Lesson 4	2D	–	–	0												
Lesson 4	3D	–	–	–												
Lesson 4 (3)					2D	+	+	0	2D	–	–	0	NOT	0	+	0
Lesson 5																
Post-Test (4)	3D	–	–	–					NOT	0	–	0				
Post-Test (4)	NOT	0	0	–	3D	+	+	–								

Student # 308	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	Dimensions			Type	Dimensions			Type	Dimensions			Type	Dimensions		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	NOT	0	0	0					NOT	0	–	0				
Pre-Test	NOT	0	0	0												
Lesson 2 (2)	3D	+	+	–	2D	+	+	0	NOT	0	0	0				
Lesson 3 (2)	3D	–	–	–	3D	+	+	–	NOT	0	–	0	2D	0	+	–
Lesson 4	2D	–	–	0												
Lesson 4	2D	+	+	0												
Lesson 4 (3)	2D	+	+	0	2D	–	+	0	2D	–	–	0	2D	+	+	0
Lesson 5	2D	+	–	0												

Post-Test (4)	2D	0	–	–					2D	0	+	+				
Post-Test (4)	3D	–	+	–	3D	–	+	–								

Student # 311	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	Integration				Integration				Integration				Integration			
	Type	Dimensions			Type	Dimensions			Type	Dimensions			Type	Dimensions		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	NOT	0	–	0					NOT	0	+	0				
Pre-Test	2D	–	–	0												
Lesson 2 (2)	2D	–	–	0	2D	+	+	0								
Lesson 3 (2)	3D	–	+	–	2D	–	+	0	NOT	0	–	0	2D	0	+	–
Lesson 4																
Lesson 4																
Lesson 4 (3)	2D	+	+	0	2D	+	+	0								
Lesson 5																
Post-Test (4)	3D	–	–	–					2D	–	–	0				
Post-Test (4)	2D	–	+	0	3D	–	+	–								

Student # 312	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	Integration				Integration				Integration				Integration			
	Type	Dimensions			Type	Dimensions			Type	Dimensions			Type	Dimensions		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	2D	–	–	0					NOT	0	+	0				
Pre-Test	2D	–	–	0												
Lesson 2 (2)	3D	+	–	–	2D	+	+	0	2D	–	–	0				
Lesson 3 (2)	2D	+	+	0	2D	+	+	0	2D	0	+	–	2D	0	+	–
Lesson 4	2D	–	+	0												
Lesson 4	2D	0	–	–												

Lesson 4 (3)	2D	–	–	0	2D	+	+	0	NOT	0	–	0	2D	+	+	0
Lesson 5	2D	+	+	0												
Post-Test (4)	2D	–	–	0					2D	0	–	–				
Post-Test (4)	3D	+	–	–	2D	+	+	0								

Student # 314	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**		**DCI**	**SP**	**CCC**
Pre-Test	2D	–	–	0					2D	0	–	–				
Pre-Test	2D	–	–	0												
Lesson 2 (2)																
Lesson 3 (2)	3D	–	–	–												
Lesson 4																
Lesson 4																
Lesson 4 (3)	2D	–	–	0												
Lesson 5	NOT	0	0	0												
Post-Test (4)	3D	–	–	–					NOT	0	+	0				
Post-Test (4)	3D	–	–	–	3D	–	+	+								

Student # 316	Model				Model Interview				Explanation				Explanation Interview			
Assignment #	**Integration**				**Integration**				**Integration**				**Integration**			
	Type	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**			**Type**	**Dimensions**		
		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC		DCI	SP	CCC
Pre-Test	NOT	0	0	0					NOT	0	0	0				
Pre-Test	NOT	0	0	0												
Lesson 2 (2)	NOT	0	0	0					NOT	0	0	0				
Lesson 3 (2)																
Lesson 4																
Lesson 4																

Lesson 4 (3)																
Lesson 5	NOT	0	0	0												
Post-Test (4)	NOT	0	0	0					NOT	0	–	0				
Post-Test (4)	NOT	0	–	0	2D	+	+	0								

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