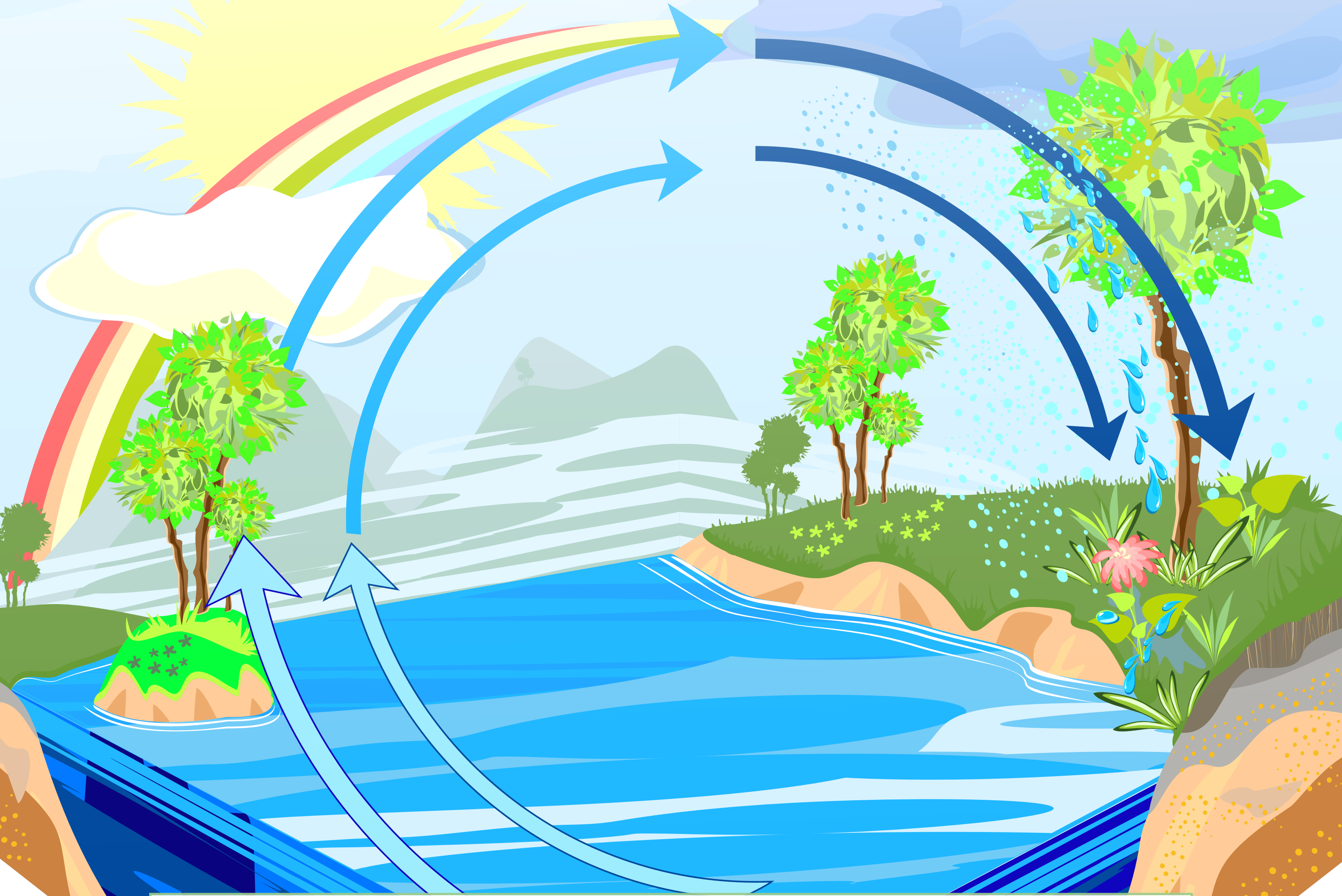
USING MODELS SCIENTIFICALLY

Scientific models help students understand the water cycle.

By Cory Forbes, Tina Vo, Laura Zangori, and Christina Schwarz



The water cycle is a large, complex system that encompasses ideas across the K–12 science curriculum. By the time students leave fifth grade, they should understand "that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot" and be able to describe both components and processes of Earth systems (NGSS Lead States 2013, p. 85). However, elementary students often articulate alternative ideas about water systems (Forbes, Zangori, and Schwarz 2015; Dickerson et al. 2007), partly because some elements of the water cycle are hard to observe (e.g., water vapor and groundwater). Scientific modeling is a productive way students can begin to think about Earth systems and to visualize and represent these unseen water-related processes.

Despite its value, scientific modeling is not widespread in elementary classrooms (NRC 2007). To support students in developing and using models to learn about water systems, we have worked collaboratively with six experienced elementary teachers to modify and enhance the eight-week Full Option Science System (FOSS) Water unit for use in third- to fifth-grade classrooms, though these strategies can be used with any curriculum or lesson plan. In this article, we discuss the importance of scientific modeling, present a set of reflective questions for students to use to guide their use of models, and describe one unit investigation focused on groundwater to illustrate effective ways to support students' scientific modeling.

Why Scientific Modeling?

Models are representations of natural systems. There are many kinds of models, such as "diagrams, physical replicas, mathematical representations, analogies, and computer simulations" that are used scientifically to "represent a system (or parts of a system) under study" (NGSS Lead States 2013, p. 52). Students should engage in modeling practices in science (Kenyon, Hug, and Schwarz 2008). These practices include opportunities to *develop* models and *use* them to make predictions, formulate questions, design and conduct investigations, explain phenomena, and communicate and justify ideas. Over time, students should also *evaluate* their models to understand how their ideas fit into a bigger picture and *revise* them accordingly to match their developing understanding.

However, students must also actively reflect on the process of scientific modeling itself. Their knowledge about scientific modeling helps them question their own thinking and reasoning as they develop, use, evaluate, and

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013): 5-ESS2 Earth Systems

www.nextgenscience.org/5ess2-earth-systems

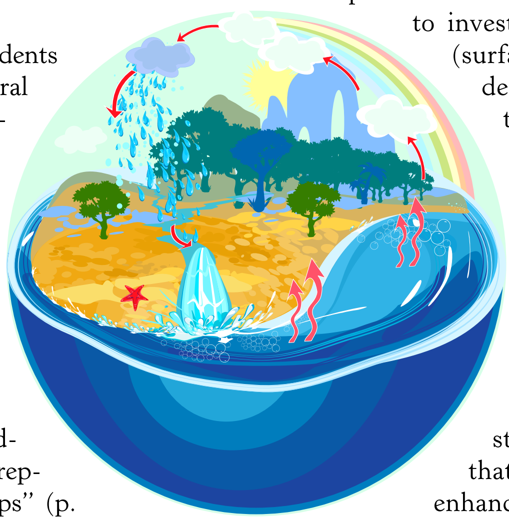
The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectation listed below. Additional supporting materials/lessons/activities will be required.

Performance Expectation	**Connections to Classroom Activity** *Students:*
5-ESS2-1 Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.	• develop models to observe the interaction of water and earth materials.
Science and Engineering Practice	
Developing and Using Models	• develop and revise a two-dimensional diagrammatic model of the water cycle to illustrate and explain the interaction of water and Earth materials.
Disciplinary Core Idea	
ESS2.A: Earth Materials and Systems • Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth's surface materials and processes.	• investigate interactions between water and a variety of earth materials to develop understanding of core concepts related to groundwater.
Crosscutting Concept	
Systems and System Models	• develop and revise a two-dimensional diagrammatic model of the water cycle to illustrate and explain the interaction of water and Earth materials.

revise their models over time. For example, students can ask and answer questions such as "How does my model connect to what I see outside?" and "What questions do my models raise?" as they use their model to design and conduct an investigation or evaluate their model in response to the question "What patterns do I observe in my data?" Questions like these help students make connections between the real world and the models they develop. They also help link the practice of modeling with other scientific practices emphasized in the *Next Generation Science Standards* (NGSS Lead States 2013).

Can Elementary Students Develop and Use Scientific Models?

Yes, they can! Models support students of *all* ages in learning about the natural world. Some may say scientific modeling is too difficult for elementary students. While scientific modeling is challenging, even for middle- and high-school students, the *Next Generation Science Standards* (NGSS Lead States 2013) state that "modeling can begin in the earliest grades, with students' models progressing from concrete 'pictures' and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships" (p. 52). Recent research, including our own, supports these claims, showing that elementary students can learn to engage in scientific modeling. However, elementary students need extra support to understand how to develop their models, work collaboratively to revise their models, and use or apply their models to the world around them. In our work, we have found that teachers can help students ask critical questions and to reflect on their model use as they are learning about systems like the water cycle.



Supporting Students' System Modeling Practices for the Water Cycle

The FOSS Water unit is an eight-week unit composed of four investigations that allow students to investigate various properties of water (surface tension, evaporation and condensation, and so on). The project team (both teachers and researchers) made specific enhancements to the FOSS Water unit to better support students to participate in scientific modeling. The purpose was not to lengthen the unit, but rather to streamline and refine it to provide students opportunities to engage in scientific modeling around core, standards-based science concepts that underlie water systems. In the enhanced unit, students are guided by an overarching investigation question: What

TABLE 1.

Reflective questions for engagement in scientific modeling.

	Modeling Practice	Student Reflective Questions	Teacher Scaffolds and Prompts
Explanation	Use	Does my model show how this phenomenon happens?	In what ways does your model show how that occurs? Explain your reasoning.
Audience	Evaluate/Revise	Who is my model for? How does my model help me justify my ideas to someone else?	Do you agree or disagree with [student] model? Why?
Connections to children's lives and experiences in the world	Develop	How does my model relate to what I see around me? Does it include my observations?	Does the process always work this way? How does your model connect to your observations from your investigation? How might this work if applied to [a related phenomenon]?

happens to water when it reaches the Earth's surface?

Through our work (Forbes, Zangori, and Schwarz 2015), we have identified three core areas, summarized in Table 1, that are important to emphasize when supporting students' work with scientific models. Doing so helps students move beyond simple drawings to develop and use models. Students' models should be based on observation and evidence as well as the phenomena in the world (i.e., connect to students' lives and experiences in the world), show how things work (i.e., provide an "explanation"), and be used by students to communicate and justify their ideas (i.e., the model "audience"). Overall, questions such as these help students reflect on the strength of their models as a representation of both their ideas and the real world and build knowledge about how systems work.

At the beginning of the unit, students develop a water cycle model as a form of preassessment (see Figure 1). During each of the four unit investigations, students are afforded opportunities to reflect on the questions in Table 1 and engage in both small-group and whole-class discussions (e.g., think-pair-share, partner-compare, and group consensus activities) to consider how their developing ideas help explain elements of the water cycle. Students evaluate and revise their water cycle models after each of the four unit investigations as they work toward a final water cycle model. The scoring rubric (see NSTA Connection) can be used to evaluate students' thinking about the water cycle based upon models students develop throughout the unit. By understanding how students think about scientific models and modeling, teachers can support students to use models effectively to learn about Earth systems.

FIGURE 1.

Pre-/Post-unit modeling task.

Constructing a Model of Water Systems

Imagine that you are on the school playground after a huge rainstorm. There are lots of places where there is water. Some places have large puddles. There is also water in ditches and moving to the drains. You go out the next day and you see that some of that water is not there anymore. You also see some areas where the water is still in larger puddles. What happened to the water that is gone? Where did it go and how did it do that? Why is some of the water still on the ground? How did it move?

On the next page in the big box draw a model of what you think happened to the water on the playground both above and below the ground in your model. Be sure to include what you think happened to water above and below the ground.

Materials

- Samples of Earth materials (gravel, sand, soil, etc.)
- Clear plastic cups
- Filter paper (coffee filters)
- Plastic beaker or syringe (100 ml capacity)
- Balance or scale
- Stopwatch (optional but helpful)

Safety Considerations

CAUTION

Samples of substrates should be free of hazardous materials. Students should wear safety gear (goggles, gloves, etc.) during this investigation. After the investigation, students should thoroughly wash their hands and clean their work areas and equipment.

Illustrative Student Investigation: Water in Earth Materials

The Water in Earth Materials investigation is a multi-day investigation that occurs in the final two weeks of the Water unit and affords students opportunities to explore groundwater, a less-easily-observed part of the water cycle with which they often struggle (Forbes, Zangori, and Schwartz 2015; Dickerson et al. 2007). In the investigation, students use simple, readily available materials provided with the FOSS module to explore the movement and retention of water in various substrates, including gravel, sand, and soil. The investigation is designed to address two related learning goals: (a) some Earth materials absorb more water than others and (b) water flows more easily through some Earth materials than others. Students explore these concepts by using graduated cylinders or syringes to add similar volumes of water to samples of various Earth materials in plastic cups with holes lined with filter paper, which are themselves placed in plastic cups without holes. They observe rates at which water moves downward through the different samples and measure the mass of each sample (cups filled with Earth materials and those that collect the water) both before and after adding water. Students record quantitative and qualitative observations (percolation rate, water volumes, descriptions of samples before and after adding water) on curriculum-provided student worksheets and are afforded opportunities to discuss their observations as a whole class. Many versions of this investigation are freely available online and it can be modified in many ways (e.g., amount of water added, the Earth materials they test, and the size of the samples) to accommodate students' questions and availability of materials. Here we present classroom examples from the enhanced Water in Earth Materials investigation to illustrate three core areas in Table 1.

FIGURE 2.

Student prompts for generating scientific explanations from their models.

I observed water moving through the gravel ____(faster/slower)____ than soil AND the sand ____(faster/slower)____ than soil because ____________

Using Models to Explain

Scientific models help students generate scientific explanations. It's helpful when students ask themselves, "Does my model show how this phenomenon happens?" We found that when students struggle to move beyond descriptions of observable trends to describe how observable water phenomena occur (e.g., explanations), support from their teachers and the curriculum is crucial. We designed elements of the lesson plans and student materials in the investigation to help students identify causal forces (such as gravity pulling water through Earth materials) in their models. For example, prompts were added to student materials (see Figure 2) to highlight both the *relationship* and the *cause* of their observations. Additionally, teachers support students to use their models to develop these kinds of explanations by helping them think about the underlying causal force that accounts for how a phenomenon occurs. Supplemental lessons used by the teachers included critical class discussion prompts, such as:

- Where does water go when added to Earth materials?
- Why does soil soak up more water than other materials?
- How does your model show *how* water moves through different Earth materials?

Teachers can use these and similar probes to support students in using their models to explain how water moves through different Earth materials at different rates.

At the end of the unit, after students have engaged with generating explanations for water in the Earth and revising their water cycle models as a postassessment (see Figure 3), we find that students generate much stronger scientific explanations for groundwater than they do at the beginning of the unit. For example, one student used his model to explain, "I think [water is] underground because it could soak through the rocky stuff…There's like little tiny spaces that it can go through and I learned when we were doing this water cycle stuff, I keep saying that the water has been soaking through because of little spaces…all over the place." In his model (Figure 3), he emphasized the

FIGURE 3.

Student's model of groundwater.

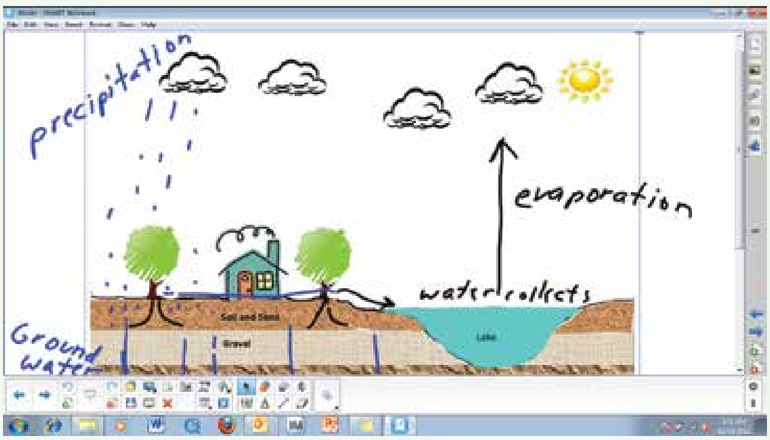
spaces between individual particles and their effect on the movement of water through Earth materials.

Considering the Audience

Models are also powerful tools to help students communicate and justify ideas. Since models are visual, they provide a "window" into students' understanding about topics such as groundwater. For models to be useful in communicating ideas, students need support in asking themselves questions such as "Who is my model for?" and "How does my model help me justify my ideas to someone else?" For justifying and communicating ideas, we enhanced the unit to give students opportunities to work collaboratively to build consensus models. Initially, individual students share their own models with one another in small groups. Later, students report from their small group conversations as part of a whole class discussion, where they are invited to use their models to describe how water moves. The final step is to create a class consensus model where all students contribute and negotiate their ideas. Teachers prompt students throughout the consensus model discussions, asking whether they agree or disagree with the ideas communicated on the individual models and why they feel that way. This allows students to make decisions about what to include on the consensus model (see Figure 4). Importantly, when students have these discussions, they are evaluating their individual models against other models, providing opportunities for students to reflect on whether their thinking has changed from one model to another. As discussions around the consensus model occur, students revise their own thinking as they consider others' ideas (Figure 5, p. 48). New ideas from peers are often reflected in students' models and thinking after these consensus discussions occur. Through this process, teachers help students consider and build on each other's ideas and use them in their own reasoning about groundwater.

FIGURE 4.

Whole-class consensus model of the water cycle.



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Students discuss their model with the teacher.

Making Connections to Students' Experiences

Scientific modeling helps students relate their observations—such as water flowing through soil, sand, and gravel—to their lives and experiences. But in order to make this connection, teachers must support elementary students, encouraging them to ask themselves "How does my model relate to what I see around me?" and "Does it include my observations?" We found that students often struggle to relate their models to their experiences, so we designed activities that support students to en-

FIGURE 5.

Sample whole-class discussion during consensus-building.

Teacher: What happens when water hits the ground?

Susan: The soil soaks it up.

Teacher: Are you saying all of this rain will soak in right where it's at?

John: We all had plants that could soak up the water in the dirt.

Teacher: So you had plants....

John: and roots

Teacher: Why?

Mark: It's nourishment for the plants.

Teacher: Does everyone agree with the water going through the ground to the roots?

Emily: I had the water going down but the roots didn't get it. It was groundwater.

Teacher: How did it get there?

Elizabeth: The plants don't need all the water. Some of it goes through the dirt and gravel underground.

Teacher: OK, does everyone agree that plants take some of it or it can collect underground?

Jordan: It can go to a lake.

Teacher: Underground?

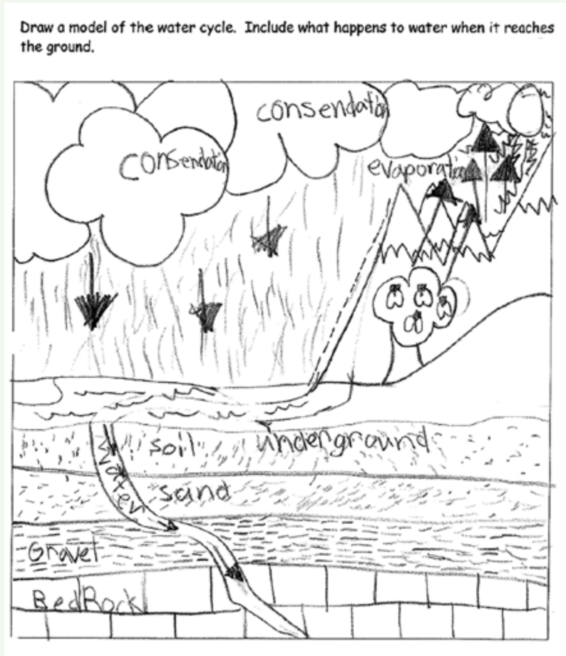
Jordan: Yeah. It moves here (in the gravel layer) and goes to the lake.

Teacher: Why?

Jordan: Because gravel has big spaces and lets the water flow through.

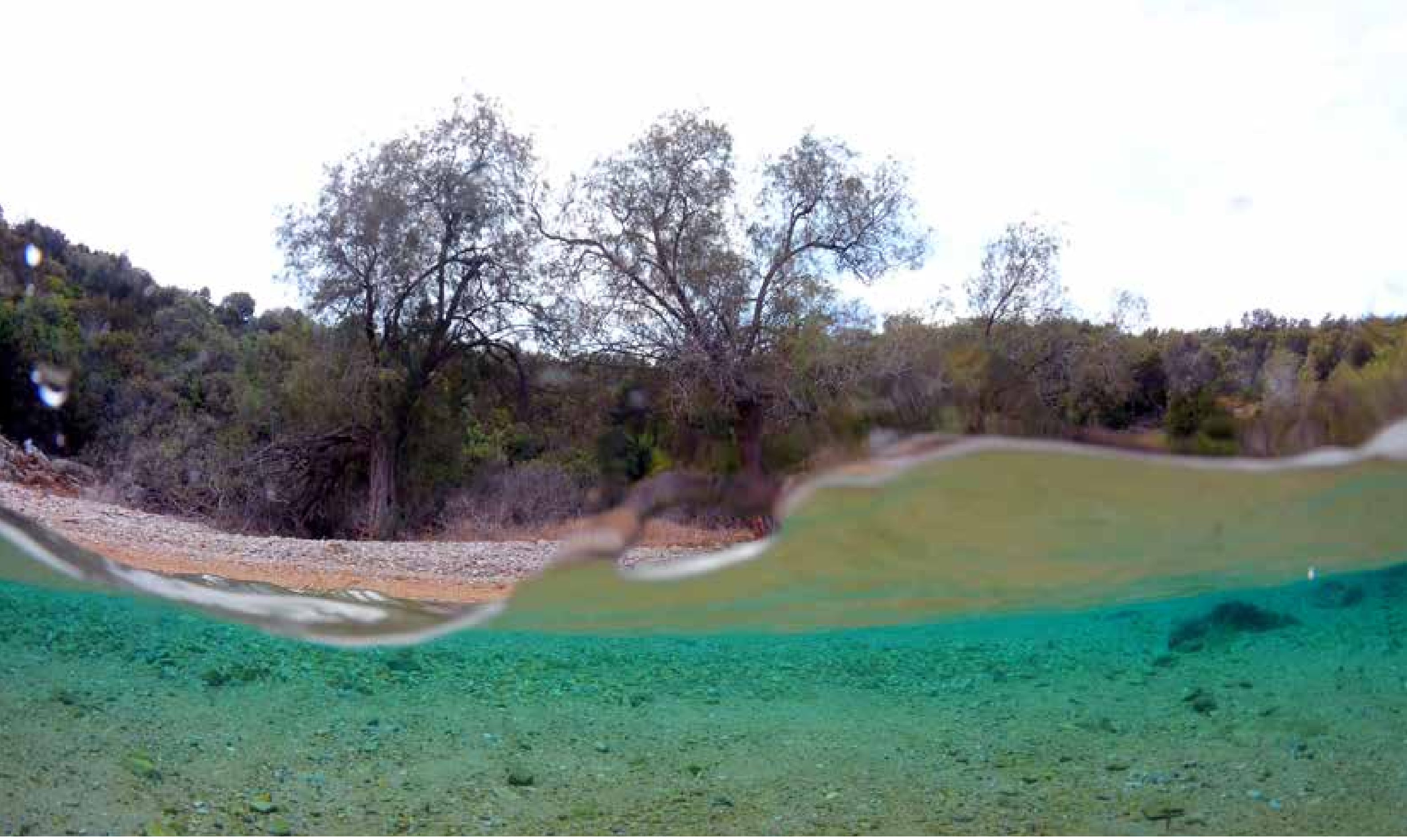
FIGURE 6.

Student's model showing water movement beneath the ground.



gage in scientific modeling as part of unit investigation. These activities include asking students to focus on *developing*, *using*, *evaluating*, and *revising* models that answer the unit investigation question, "What happens to rain when it reaches the ground?" For example, teacher prompts were added to the lesson to encourage students to pay particular attention to how the investigation tasks reflected real-world phenomena.

During the investigations, teachers probed students' thinking through questions such as "Does the process always work this way?" and "Does it work this way in different places?" After conducting the Water in Earth Materials investigation, students use their observations and data to draw diagrams showing how water moves through soil, sand, and gravel and recorded their data. After students complete their diagrams, they then consider how their observation and evidence of water moving through Earth materials relates to their full water cycle model. They are given the opportunity to revise their water cycle model to reflect their new ideas about water underground. As Jessi explained about her final model, "It's fun to draw the water cycle… [because] it's the world...What happens in the world." This was expressed in her revised water cycle model (see Figure 6), which included the different layers underground and the different ways in which water flows down through these layers. By making this connection between their observations and the water cycle, students are better able to show how their models relate to the real world. Through this process, teachers help students relate their models to other phenomena in the world and their own lives by listening to students' experiences and supporting them to connect their ideas to those experiences.



Final Thoughts

Scientific models can be powerful tools that help students at *all* age levels make sense of natural systems such as the water cycle. The reflective questions and strategies presented here are important to help students move beyond simply drawing pictures to constructing models and using those models to interpret and explain the world around them. In particular, for the water cycle, these models and the practice of scientific modeling can help students confront common alternative conceptions they often hold (Forbes, Zangori, and Schwartz 2015; Dickerson et al. 2007) and learn to engage in scientific practices to advance their thinking. Using these classroom approaches will help elementary students begin developing the ability to use models scientifically, which creates a strong foundation of science literacy. Doing so enhances their understanding of natural systems and also promotes their participation in other scientific practices emphasized in the *Next Generation Science Standards* (NGSS Lead States 2013). ■

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NSTA Connection

Visit *www.nsta.org/sc1510* for the rubric.