The Benefits of Scientific Modeling

Constructing, using, evaluating, and revising scientific models helps students advance their scientific ideas, learn to think critically, and understand the nature of science.

By Lisa Kenyon, Christina Schwarz, and Barbara Hug

Have you ever wondered why we construct scientific models? Most likely, you've seen your share of volcanic eruptions made from vinegar and baking soda at elementary science fairs, asked students to make solar system mobiles, or perhaps asked students to represent the parts of a butterfly life cycle with different kinds of pasta. Are these scientific models? Do they help students develop their scientific ideas, think critically, and understand the nature of science?

A *scientific model* is a representation of a system that includes important parts of that system (along with rules and relationships of those parts) to help us think about and test ideas of the phenomena. Some familiar examples of scientific models include the particle model of matter, a light ray model, the water cycle, and a food web model that shows interactions between organisms. Models can be physical—such as the atom model—or conceptual, such as the water cycle model.

When considering the volcano and the butterfly pasta models mentioned earlier, we see that they cannot easily be used as scientific models, since they do not accurately predict or explain the phenomenon of volcanic activity or the cyclical nature of the butterfly life cycle. They represent an idea but they do not allow us to test an idea or extend it. The solar system model describes the order and type of planets in our solar system, so it is helpful for understanding these components, though the model is limited in the sense that it does not always accurately represent other aspects such as the motion around the Sun and the distances between planets.

Even better than *knowing* about powerful models is *knowing* and *doing* scientific modeling. What we mean by modeling is the experience of constructing, using, evaluating, and revising scientific models and knowing what guides and motivates their use. When students are engaged in scientific modeling, they are able to notice patterns and develop and revise representations that become useful models to predict and explain—making their own scientific knowledge stronger, helping them think critically, and helping them know more about the nature of science.

To demonstrate this, we describe a four- to six-week unit on evaporation and condensation for fifth-grade students that incorporates four essential aspects of scientific modeling. In the unit, students experience various kinds of scientific modeling as they construct, use, evaluate, and revise evaporation and condensation models to understand how a *solar still* (a device used to distill water using the Sun as a heat source) cleans dirty water.

Initial Explorations

To begin, in advance, the teacher prepares a solar still from a two-liter bottle and other supplies. To assemble the still, cut off the top of a two-liter soda bottle. Cut a narrow slit in each side of the bottle, and insert a large craft stick across the bottle through the slits. The craft stick provides a platform for the cap that collects the evaporated and condensed water. Tape the collection cap to the craft stick to prevent it from falling into the "dirty" water (water with soil or coffee grounds mixed in). Pour approximately one cup (250 mL) dirty water into the bottle. Cover the bottle with plastic wrap and secure it with a rubber band. Finally, place a weight (such as a metal marble) in the center of the plastic wrap, which helps the plastic wrap slope toward the collection cap in the bottle. (For best results, place the still in a warm place or use hot water.)

After about a week, evaporated and condensed water will have collected in the bottle cap, at which point the teacher presents the solar still to students. As the teacher presents the still, she asks students to make observations and to answer the questions, "Would you drink the liquid in the bottle cap?" and "Do you know what that liquid is and how it got there?" Most students don't know how the water got there and are hesitant to commit to an answer, so the teacher explains that over the next few days they will be doing more explorations to find out how the clear liquid got in the bottle cap.

The next day, students explore phenomena similar to the solar still to add to their knowledge base, such as water evaporating off of a plate and from a working humidifier. Again, the teacher asks students to think about these phenomena and try to explain what happens when water comes in contact with air. Usually, students bring up the idea of the water disappearing "into the air" or "into clouds," the process of evaporation ("the water evaporated"), the ideas of gases ("evaporation lifts it up [water] as a gas into the air"), and the idea of temperature ("the water evaporated because it was exposed to air and thermal energy"). Giving students opportunities to observe and share their initial ideas is helpful background experience when they are asked to create an initial model of evaporation on the following day.

Construct a Model

On the third day, the teacher leads the whole class in a discussion about the purpose of models and why it is important to construct initial models. The teacher explains that one way of making sense of ideas is by testing them and sharing them with each other for feedback. In order to advance and share ideas, it is helpful to represent them in some way, such as through a model. The goal is to continue to think through and revise the models with respect to evidence so that the final model is the most accurate and predictive model.

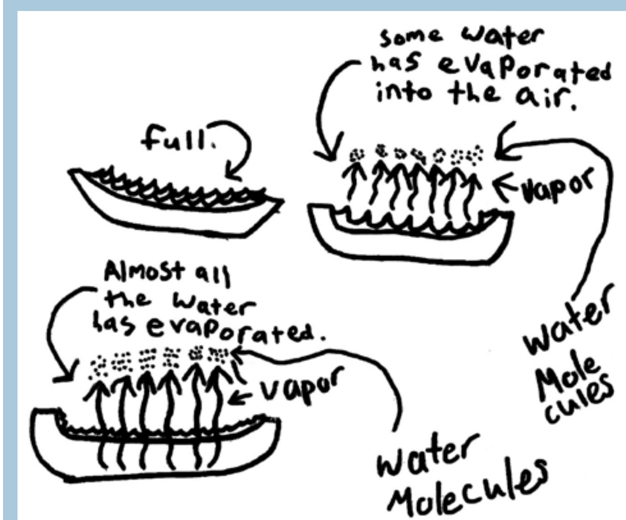
After this discussion, students create initial models, in this case diagrams, which explain their observations of evaporation. Students are asked to draw a "before, during, and after" picture of evaporation to show how it happens over time. They are told that the model should capture not just "what happens to the water" (description) but also "why or how it happens" (an explanation or a process). One student's initial diagram model is shown in Figure 1.

Test the Model

The next phase is to test the models to determine which one is the most accurate and predictive model. The teacher explains that even though the students made some creative initial models, the models need to be tested by collecting data (i.e., evidence) to support their ideas, and students do so by conducting multiple experiments. For example, students use an electronic scale to measure the weight of water at one-minute intervals and observe the weight of the water decreasing as water evaporates into the air; they use cobalt chloride strips to detect the presence of water near the humidifier and determine if there is any water in the air; and they use Pasco humidity detectors to measure humidity when they have a cup of water (cold and hot) enclosed in a covered container. Through these experiments, students discover that there is water in the air even though they cannot visually see it and that the humidity (or amount of water in the air) can vary depending on the proximity to a water source. For example, students find that the amount of water in the air increases when the probe or strip is closer to the humidifier and decreased when the probe or strip was farther away. When they investigate the effects of water temperature on the amount of water in the air, they find that the humidity levels increase faster with warmer rather than cooler water.

Figure 1.

Initial model of evaporation



Evaluate the Model

After these experiments, students return to their initial diagram models of evaporation and evaluate the models. The teacher and students discuss the criteria they will use to evaluate their models. Most often, students cite clarity and scientific accuracy as the two most important criteria by which to evaluate a model. However, there are additional factors to consider as well, such as use of evidence gathered from investigations, the model's consistency with other scientific ideas, whether it includes the most important features of the phenomena, and how the model shows the clarity of these ideas with representations (e.g., arrows and labels). When students are comfortable with these ideas, they make changes to their models in light of the data they have collected, taking into account their evaluative criteria. Some of the changes that students make to their evaporation models are including labels and arrows to refer to water moving away from the plate and spreading out as it moves from the plate to the air. Other students write a few sentences to further explain "how" the invisible water is moving through the air.

Test the Model Against Other Ideas

Once students have evaluated their models, they examine existing scientific information about evaporation and view computer simulations of evaporation (and later condensation) from the Molecular Literacy Project (see Internet Resources). Students explore the simulation in pairs and answer the following questions, *"What is the water made of? How does it look as liquid water? What happens when that liquid comes in contact with the air? What happens to the liquid water in the air? How does adding heat and taking heat away change what happens to the liquid water and the water in the air?"*

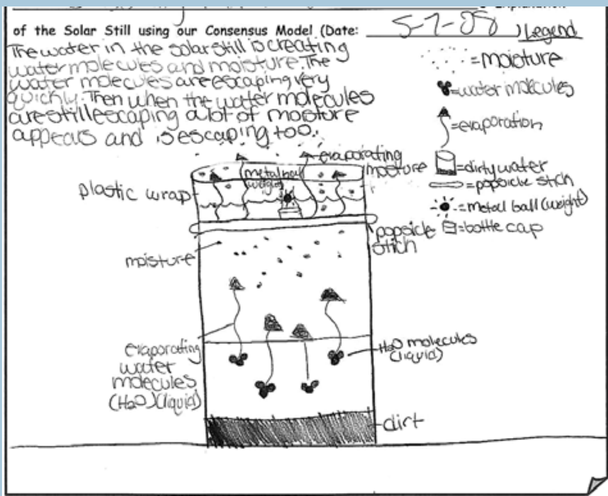
Revise the Model

After these experiences, students return to their model of evaporation and evaluate it again, taking into account the new information they have learned from the simulations. Students compare models among groups and, together, construct one consensus model for the whole class to use. In this case, the students' consensus model included showing changes over time (indicating a process), using arrows and explaining "how" the water disappears from the plate, and including descriptions of the particles going into the air and arrows that show change of state. Students also decided to remove as-

Figure 2.

Applying consensus models.

In this diagram, students apply their consensus models of evaporation and condensation to explain what happens in the solar still.



pects that were not essential to the model, such as the drawing of the table that was holding the plate.

The process of creating the consensus model allows students to engage in the social element of the modeling practice. During this process, students usually make such comments as "We are sharing our ideas to develop the best model" and "It is easier to keep their model simple rather than adding lots of details." Students shared their ideas and were able to talk through the evaluation process as they put together the best model of evaporation. Students paid attention to the simplicity of the model, the most important features, scientific accuracy, and communicative aspects of labeling and descriptions. By engaging in the revision practice, students discovered for themselves how models can change as new understandings develop.

Use a Model to Predict or Explain

Finally, students use the consensus model of evaporation to explain other evaporation phenomena. Students are given a sheet with a list of other phenomena such as a color marker without a cap drying up, paint or perfume drying, and the solar still. The students are prompted to use their model of evaporation to explain how the other phenomena work. Students can work on these examples individually or in small-group discussions. This part of the unit is important for determining whether students are able to use their model of evaporation to explain these phenomena. For example, in answering the question about the colored marker, one student said, "In the model of the cup of water with no lid, the water is evaporating into water vapor or a gas, and that's what happens with the marker because it's a liquid, and all liquids evaporate into a gas form or a water vapor form."

Repeat Modeling Sequence

We repeat this modeling sequence to make a model of condensation—where students are asked to think about from where the water drops on the plastic wrap of the solar still come. What happens when the gas comes in contact with a surface and forms drops? Students construct initial models of condensation, test the models by investigating what happens on the outside of a soda can as it first comes out of the refrigerator, weigh a soda can before and after condensation, make observations of changes, and use a Pasco probe to measure humidity changes. Students continue to evaluate, test against other ideas with computer simulations, and eventually build a consensus model of condensation.

At the conclusion of the unit, students apply their consensus models of evaporation and condensation to answer their initial question: "*Would you drink the liquid that came from the dirty water?*" The students are asked to draw a diagram of the solar still using their consensus models to explain what is happening within the solar still (Figure 2). In this way, we see how students use scientific ideas developed within the unit. We see them applying their understanding of evaporating particles, water molecule movement, free particles, and moisture in the air. These ideas are shown by symbols such as water vapor bits of dots, magnifying glasses to show water vapor present, arrows and wavy lines to show motion of the water bits, and labels.

Summing Up

We have found this instructional sequence—constructing a model to explain a phenomena, testing the model, evaluating the model, testing the model against other ideas, revising the model, and using the model to predict and explain—to be effective in helping students learn key scientific concepts about evaporation and condensation *and* for developing their understanding about modeling. In Figure 3, we suggest how the instructional modeling sequence can be integrated into other content areas. We found that students enjoyed drawing, writing, and even revising their own science ideas when modeling. Throughout this instructional sequence, students are doing hands-on activities combined with thinking about scientific explanations and incorporating them into their models. This modeling approach allows a wide range of students to meaningfully participate in science. ■

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Figure 3.
Modeling practices in different curricular contexts.

Modeling Practices	Construct	Evaluate	Revise	Use
Insect life cycles	Students draw a diagram of a life cycle.	Students evaluate their models using data collected from an observational study of a caterpillar over time.	Using data from their observations, students add in different larval stages into their life cycle model.	Students use the model to predict when a butterfly will emerge from the chrysalis.
Electricity	Students draw an electrical circuit describing how a lightbulb can light.	Students evaluate their model using data collected from experiments using two bulbs and multiple wires.	Student revise their models using data collected from multiple tests of lighting the bulbs.	Students use their model to predict how multiple lights could be made to turn on.
Condensation	Students draw a diagram of how dew appears on grass. What happens to water on a cold bathroom mirror following a hot shower.	Students evaluate their models using evidence of water vapor in the air, and scientific ideas introduced through simulations.	Students revise their models after analyzing data they collect. They construct a class consensus model from these revisions.	Students apply their consensus models to additional contexts that involve condensation (i.e., a cold soda can, a bathroom mirror, and a solar still).
Light	Students construct a three-dimensional model for how humans see objects with light.	Students evaluate the light model using the data they collected about shadows.	Students revise their light model to account for light phenomena using data collected about scattering, reflection, transmission, absorption, and color.	Students apply the light model to familiar phenomena (shadows) as well as other unfamiliar concepts.
Particle Model of Matter	Students construct models to explain how a smell can get to their noses.	Students evaluate their models by using evidence from readings and experiments (such as different liquids changing to gases).	Students constantly discuss different ways of changing their models to enhance the explanatory power of the model.	Students use their models to explain the behavior of different gases (such as air compression and expansion of ammonium vapor).

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Internet Resource
The Molecular Literacy Project
http://molo.concord.org/

Connecting to the Standards
This article relates to the following *National Science Education Standards* (NRC 1996):

Content Standards
Unifying Concepts and Processes (K–8)
- Evidence, models, and explanation

National Research Council (NRC). 1996. *National science education standards*. Washington DC: National Academy Press.