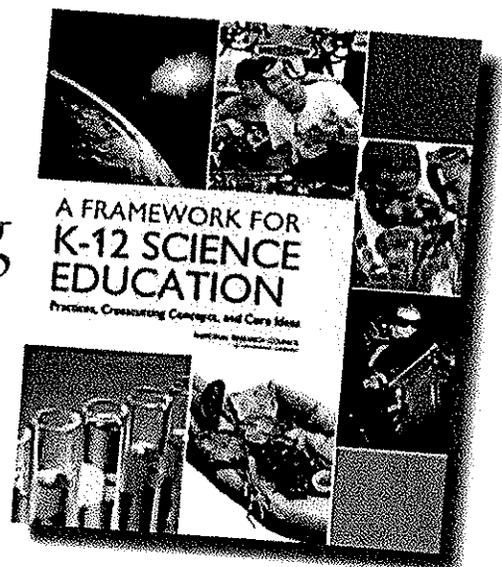


Engaging Students in Scientific Practices: What does constructing and revising models look like in the science classroom?

Understanding A Framework for K-12 Science Education

By Joseph Krajcik and Joi Merritt



The Next Generation Science Standards (NGSS)—now in development—will be based on *A Framework for K-12 Science Education* released by the National Research Council last summer. The NGSS will use four key ideas from the *Framework*: (1) a limited number of core ideas of science, (2) the integration or coupling of core ideas and scientific and engineering practices, (3) crosscutting concepts, and (4) the development of the core ideas, scientific practices, and crosscutting concepts over time.

In the December issue of *The Science Teacher*, Rodger Bybee provided an overview of the Scientific and Engineering practices and showed how they are a refinement and further articulation of what it means to do scientific inquiry in the science classroom (2011).

The *Framework* identifies seven scientific and engineering practices that should be used in science classrooms. These practices reflect the multiple ways in which scientists explore and understand the world and the multiple ways in which engineers solve problems. These practices include:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics, information and computer technology, and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

In this article, we look in-depth at scientific practice #2—developing, evaluating, and revising scientific models to explain and predict phenomena—and what it means for classroom teaching. Models provide scientists and engineers with tools for thinking, to visualize and make sense of phenomena and experience, or to develop possible solutions to design problems (NRC 2011). Models are external representations of mental concepts. Models can include diagrams, three-dimensional physical structures, computer simulations, mathematical formulations, and analogies. It is challenging for learners to understand that all models only approximate and simplify how the entities they represent work, yet models provide a powerful tool of explaining phenomena. It's critical that a model be consistent with the evidence that exists, and that different models are appropriate in different situations depending on what is being explained. If the model cannot account for the evidence, then the model should be abandoned (Schwarz et al. 2009).

A Framework for K-12 Science Education states that by the end of the 12th grade students should be able to:

- Construct drawings or diagrams as representations of events or systems
- Represent and explain phenomena with multiple types of models and move flexibly between model types when different ones are most useful for different purposes.
- Discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect

a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality and explanatory power.

- Use (provided) computer simulations or simulations developed with simple simulation tools as a tool for understanding and investigating aspects of a system, particularly those not readily visible to the naked eye.
- Make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions. (NRC 2011, p. 3-20).

What does this practice mean for classroom instruction? What does it mean that the practices of modeling will be blended with core ideas? Perhaps the biggest change the modeling practice brings to classroom teaching is the expectation for students to construct and revise models based on new evidence to predict and explain phenomena and to test solutions to various design problems in the context of learning and using core ideas. Students will be engaged in what it means to do science because this is one major activity that drives scientific work and thinking.

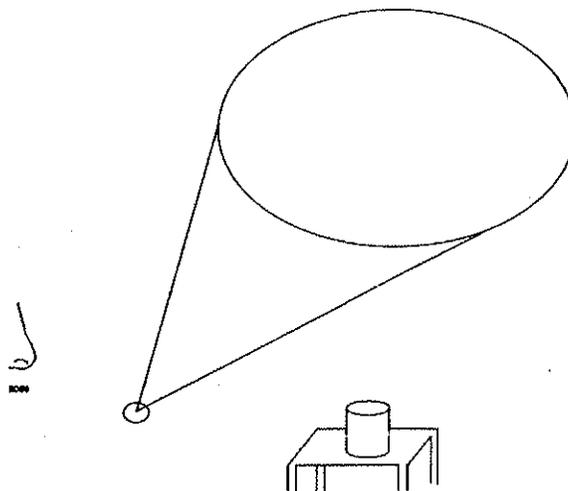
Often in science class, students are given the final, canonical scientific model that scientists have developed over numerous years, and little time is spent showing them the evidence for the model or allowing them to construct models that will explain phenomena. As a result, often learners do not see a difference between the scientific model and the phenomena the model is predicting and explaining, or the value of the model for explaining and finding solutions. The *Framework* emphasizes that multiple models might explain a phenomena and that students should improve models to fit new evidence. It is important that science teachers engage students in the modeling process. What do modeling practices look like in the classroom? What are teachers expected to do in their teaching?

It is important for students to construct models that explain phenomena, show how their models are consistent with their evidence, and explain the limitations of those models. Following is one example of what this might look like in a middle school classroom. Imagine a sixth-grade class engaged in exploring core ideas from the *Framework's* PS1.A: "Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide." (NRC 2011, p. 5-4). Blending this core idea with the practice of constructing and revising models, students could be asked to draw a model of how the odor gets from the source to your nose (Merritt and Krajcik 2012; Merritt 2010). Students are asked to complete the task described in Figure 1.

Figure 1.

Drawing a model of an odor.

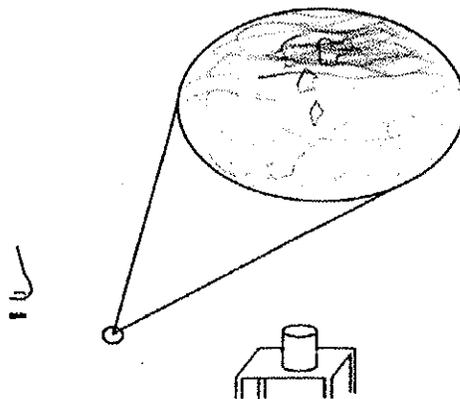
Imagine that you have a special instrument that allows you to see what makes up odor. The large circle in the drawing below represents a spot that is magnified many times, so you can see it up close. Create a model of what you would see if you could focus on one tiny spot in the area between the jar and your nose.



Label the parts of your model, so someone who looks at it will know what the parts represent.

Figure 2.

A student model at the initial stage.



4. Label what the parts in your drawing represent.

Figure 3.

A student's second attempt at drawing a model of air and odor.

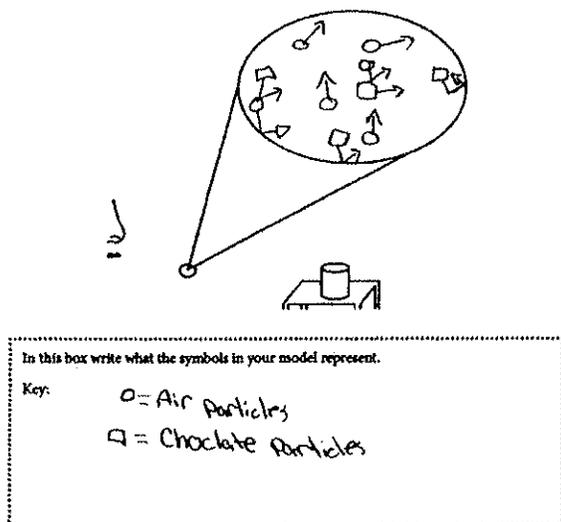
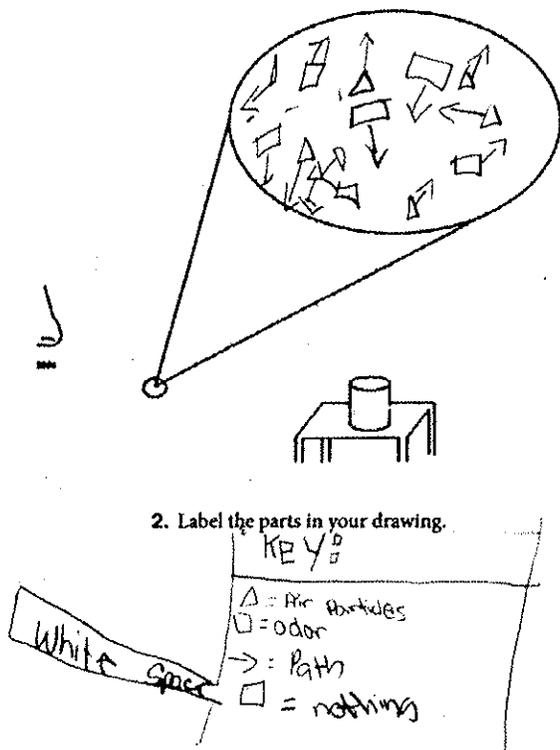


Figure 4.

A student's model at the end of the unit.



Students are asked to make this model three times during an eight-week unit that focuses on Core Idea PS1.A. In each case, students need to include a key, the drawing, and an explanation of the drawing. Students construct their first model on the first day of the unit. Students walk into class, and the teacher opens a container that contains a strong odor (typically menthol) and asks the students to make a drawing (a representation) of how the odor gets from the container to their noses. The students have had no formal instruction on the particle nature of matter. All they are expected to do is draw a feasible model consistent with the evidence they might see if they had a very powerful instrument that would allow them to “see” the odor.

Typically at this initial stage, students' models do not match the scientific model. This is perfectly okay as long as the student model is reasonable and feasible. As previously reported (Novick and Nussbaum 1978), students initially draw a continuous or cloud model to represent the air and the odor. Figure 2, page 11, shows an example of what students typically draw.

Next, students complete a series of investigations in which they explore properties of gases. For instance, they use syringes to experience that gases are compressible and expandable: You can add gas to or remove it from a container with a fixed volume without changing the shape of the container. Using these and related experiences, students are again challenged to create a new model of matter to explain how an odor can get from a source to their noses and what they would see if they had a special instrument that “sees” odor. Now, however, their models must be consistent with the evidence they have regarding the properties of gases (i.e., gases can be expanded and compressed and can be added to or taken away from a container with a fixed volume). As Figure 3 shows, students now draw models that are more particulate in nature.

Although this model is still not consistent with the full scientific model, it has features consistent with scientific models. The student now visualizes air and odor to consist of tiny particles too small to see; the particles have space between them and travel in straight lines until they collide with other particles. There are some concerns with the model. For instance, the model shows particles that collide with the imaginary side of the magnified section. The model, however, is consistent with the evidence the student has collected: that a gas can be compressed, expanded, and added to or taken away from a container with a fixed volume.

Throughout the unit, students continue to collect additional evidence about the properties of gases. For instance, students explore the effect of temperature on how fast a gas travels by investigating the time it takes ammonia vapor to change indicator paper blue when a test tube containing drops of ammonia is in a warm versus cool water bath.

Once students have developed their own models, through careful scaffolding by the teacher, they also develop a class consensus model and explore computer simulations to develop a rich and integrated model of the structure of gases, liquids, and solids as being particulate in nature.

As Figure 4 indicates, at the end of the unit most students have developed models more consistent with the scientific model. The model in Figure 4 shows that gases (air and odor) are made up of tiny particles too small to see, have space between them, move and collide into each other, and change direction as a result of these collisions. There is no indication of the particles colliding with the imaginary walls of the magnified section. Moreover, the student clearly points out there is nothing between the particles. These understandings form a foundation that can be used to build more sophisticated models of the structure of matter. What is important to realize in these examples is that these student models account for all the evidence they have regarding the properties of gases. The student was not told the features of the particle model but rather developed the particle model through carefully supported modeling activities in which students built models based upon evidence. This is the major feature of the modeling practice: developing and revising models.

Concluding Comment

Because *A Framework for K–12 Science Education* emphasizes fewer ideas developed across K–12 science curriculum and blended with the use of scientific practices and crosscutting elements, Next Generation Science Standards will present a more coherent view of science education that will engage students in the process of doing science.

The U.S. science curriculum has long suffered from being disconnected and presenting too many ideas too superficially, often leaving students with disconnected ideas that cannot be used to solve problems and explain phenomena they encounter in their everyday world. John Dewey expressed this concern in 1910, and we continue to strive so that students learn science in a more coherent manner.

“Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter.” (Dewey 1910)

By focusing on big ideas blended with practices and crosscutting elements over time, the *Framework* and Next Generation Science Standards strive to avoid shallow coverage of a large number of topics and allow more time for students to explore and examine ideas in greater depth and use those ideas to understand phenomena

they encounter in their lives, while engaging in an “effective method of inquiry.” The modeling practices and the example described in this article demonstrate science teaching as “effective method of inquiry into any subject-matter.” This focus on fewer ideas blended with scientific and engineering practices will allow teachers and students time to do science by engaging in a range of scientific practices, including creating and revising models that can explain phenomena and that change as more evidence is collected. Imagine the type of student who emerges from 12th-grade science education after repeatedly experiencing instruction since elementary school that supported them in constructing and revising models to explain phenomena! These students will form a different breed of high school graduates who view science as an “effective method of inquiry” and who will serve as productive 21st-century citizens to create a sustainable planet. ■

Joseph Krajcik (Krajcik@msu.edu) is a professor of science education, and Joi Merritt (jmerritt@msu.edu) is a postdoctoral researcher focusing on science education, both at Michigan State University. Krajcik served as Design Team Lead for the Framework and currently serves as Design Team Lead for the Next Generation Science Standards.

References

- Bybee, R. 2011. Scientific and engineering practices in K–12 classrooms: Understanding *A Framework for K–12 Science Education*. *Science and Children* 49 (4): 10–15.
- Dewey, J. 1910. Science as subject matter and method. *Science* 31 (787): 121–127.
- Merritt, J. 2010. *Tracking students' understanding of the particle nature of matter*. Unpublished doctoral dissertation. University of Michigan, Ann Arbor, MI.
- Merritt, J., and J.S. Krajcik. 2012. Supporting students in building a particle model of matter. In *Structural Concepts of Matter in Science Education* (forthcoming), eds. G. Tsaparis and H. Sevian. Dordrecht, Netherlands: Springer.
- National Research Council (NRC). 2011. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
- Novick, S., and J. Nussbaum. 1978. Junior high school pupils' understanding of the particulate nature of matter: An interview study. *Science Education* 62 (3): 273–281.
- Schwarz, C., B. Reiser, E. Davis, L. Kenyon, A. Acher, D. Fortus, Y. Shwartz, B. Hug, and J.S. Krajcik. 2009. Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching* 46 (1): 232–254.