



# Developing and Using Models to Make Sense of Science

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## Introduction

Science educators are probably quite familiar with models, and so are K–12 students and their families. People often use models in their everyday lives. Maps are models of roads and locations. A globe is a model of Earth. Model cars, airplanes, and trains are tiny replicas of vehicles. All models are representations of something else—an idea, an object, an event, a process, a system—and act as substitutes for the real things.

## The Role of Models in Science

Models are central to the process of understanding, doing, and communicating about science. Scientists use models to make predictions and construct explanations for how and why natural phenomena (i.e., observable facts and events) happen. For example, weather maps are models that scientists use to predict weather patterns. Scientific models of atmospheric and oceanic phenomena contribute to an understanding of global climate change. Models also allow scientists to go beyond the visible world to describe objects that are too large or small, too slow or quick for the human eye; things that don't exist anymore; things that have never been created; and ideas too difficult to communicate in words.

Engineers rely on models, too. They use models to visualize and refine designs and to communicate a design's features to others. Models help engineers evaluate existing systems for flaws and test possible solutions to problems. Engineers also use models to test prototypes and to analyze systems and designs for their strengths and limitations. For example, crash tests involving dummies are models that allow engineers to assess the safety of car designs.

Scientific models are fundamentally the same as models used outside of science and engineering. They are representations of real-world phenomena. Scientific models, also known as “mental models,” are expressions of internal ideas or thoughts that scientists have about how the world works. Conceptual models are the external articulation of scientists' mental models. Scientists' ideas are made visible through many types of models.

Scientific models range from a simple diagram illustrating an organism's life cycle to a computer simulation that replicates the complex process of protein synthesis. Models can be analogies. If a person understands how water moves through a hose, he or she can use that understanding to think about blood moving through vessels. Models can be mathematical formulas that explain what happens when variables change. A model of the solar system is a physical replica of the planets orbiting the sun. Scientific models represent something about the structure, behavior, and function of objects, processes, or events that happen in the world.

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Practicing scientists draw on models already developed by others in the field, but much of the power of models comes from developing them. Developing models helps scientists visualize complex concepts, understand problems, and communicate new ideas. They evaluate and refine models through an iterative cycle of comparing their predictions with what they discover. When new evidence is uncovered that a model can't explain, scientists modify the model.

## Developing and Using Models in K–12 Education

The work of student scientists mimics that of real scientists and engineers. Goals of science education envisioned by the writers of *A Framework for K–12 Science Education* (2012) include cultivating students' scientific habits of mind, developing their capacity to engage in scientific inquiry, and teaching them how to reason in a scientific context. An emphasis on practices is one of the defining shifts in the *Next Generation Science Standards* (NGSS) (2013), written in response to the Framework. The following eight practices are deemed essential for all K–12 students:

1. Asking Questions and Defining Problems
2. Developing and Using Models
3. Planning and Carrying Out Investigations
4. Analyzing and Interpreting Data
5. Using Mathematical and Computational Thinking
6. Constructing Explanations and Designing Solutions
7. Engaging in Argument From Evidence
8. Obtaining, Evaluating, and Communicating Information

As seen above, the NGSS specifically call out models as a critical component of K–12 science education. Students are expected to use models to illustrate, predict, and explain phenomena, just as scientists do. There are two parts to this objective: using models and developing models.

K–12 students are introduced to many classic scientific models. The Bohr model helps students understand the components of an atom. A water cycle model illustrates the movement of water on, in, and under the earth as well as the processes involved. Food web diagrams show relationships of organisms in an ecosystem and the energy flow between them. The periodic table, Newton's laws, and the continental drift model are additional examples of familiar models used by student scientists.

In addition to notable and familiar scientific models, lesser-known representations of ideas, methods, and phenomena can help students visualize and comprehend observations and events. For example, we might draw particle-level models of gases to help explain that gas is matter and can be used to inflate a ball. Or we might use a density continuum, a force diagram, or mathematical formulas to explain why some objects sink or float in water.

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Beyond using the models created by others, the practice of modeling is an important science skill for students to learn and practice. The process of constructing models aids students in making sense of the science behind a phenomenon. When students practice developing, testing, and revising their own scientific models, they are prompted to articulate and communicate their own thoughts and ideas about how things work. This contrasts with striving to understand the thought process of another person when working with an already established model. It is through the experience of modeling that students learn to think like scientists and arrive at a deeper understanding of scientific concepts.

Developing and using models (Practice #2) can help teachers use and connect other NGSS practices into a dynamic, interactive set. For example, students' observations and questions (Practice #1) are mediated by models. Models assist them in designing their own investigations to answer questions (Practice #3). Models are filters students use to interpret data (Practice #4) as they look for patterns or use math formulas to think about the effects of changing variables (Practice #5). Models help students make sense of and construct explanations for phenomena (Practice #6). Students use argumentation (Practice #7) to communicate information about models and evaluate them (Practice #8).

## Helping Student Scientists Develop and Use Scientific Models

Science teachers work to advance their students' mental or internal models and assist them in expressing their ideas. All students have ideas. Through modeling, they can further establish, extend, and refine incomplete or incorrect ideas. Modeling also helps students understand the nature of science and allows them to improve skills such as systems thinking and evaluating ideas.

Christina Schwartz and Cynthia Passmore share their passion for using modeling and models at all grade levels in an NSTA webinar entitled *Preparing for NGSS: Developing and Using Models* (2012). Schwartz and Passmore highlight the idea that the key elements of model-based inquiry in a classroom include cycles of developing, evaluating, and revising models. By carefully sequencing lessons, teachers can provide students with optimal learning experiences.

Although there isn't just one way a teacher can successfully use modeling in a classroom, here is a recommended sequence to try:

1. Students are introduced to a phenomenon that is relevant and interesting.
2. The class develops a focus question.
3. Students develop initial models to make predictions about what they think will happen or to try to explain the phenomenon.
4. Students design and carry out investigations to gather data.
5. Students use their findings (evidence) to elaborate on the ideas represented in their initial models. They make revisions.
6. Students explore theoretical ideas to clarify their understanding of the science involved.

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7. Students use their findings (evidence) to elaborate on the ideas represented in their modified models. They make additional revisions.
  8. Students share their models with one another and develop a class (consensus) model.
  9. Students apply what they have learned to a novel, but related phenomenon or problem to show their understanding.

The NGSS outline a coherent progression of developing and using models in grades K–12. In grades K–2, modeling incorporates students’ prior experiences and progresses to include using and developing models. These models include diagrams, drawings, physical replicas, dioramas, dramatizations, and storyboards that represent concrete events or design solutions. In grades 3–5, modeling advances to building and revising simple models. Models are used to represent events and design solutions. In grades 6–8, modeling builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. In grades 9–12, modeling adds to the K–8 experiences and moves students forward to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

### **An Example of Using Modeling**

I facilitated a workshop with a group of adult learners, including teachers, school district-level staff, and informal science educators. We explored systems and system models. Because systems are complex things, it’s often helpful to use models to represent them. My goal was to give participants a foundational understanding of what systems are and how they can be represented using models.

After building a common background and understanding of systems, small groups of participants investigated a set of seven different models describing the life cycles of frogs. They evaluated the usefulness of the models thinking through a variety of questions posed about frogs: How do frogs reproduce? How do frogs obtain the matter they need to grow? And so on. This helped participants recognize the benefits and limitations of various models. Typically, a model will only deal with some aspects of the phenomenon in question.

In the last step of the science investigation, participants had a chance to dive deeply into a system by creating and refining a diagram of a system—a system model—on their own. I provided a variety of systems for them to explore, including fidget spinners, model airplanes, and remote-controlled toy cars. They made multiple iterations of their models and thought about the parts of the system they didn’t fully understand as black boxes. By creating a model, they were pushed to think more deeply about their system, its components, and what those components do. It helped them figure out where they had gaps in their understanding and provided targets for future research.

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The participants learned that models enable us to explore things that we don't have access to and allow us to manipulate factors we otherwise could not. Perhaps more importantly, they learned that models help us make our thinking visible to others, which supports the collaborative sense-making, model evaluation, and model refinement that is characteristic of science and engineering. Although we were together for only a few hours, we all had a deeper understanding of developing and using models by the end of the workshop.

## Using Modeling in Your Classroom

**T**hink about how the sequence of model-based learning you read about earlier and the NGSS grade-level expectations for modeling would work in your classroom. Would it be similar to what you already do, or would it require a big shift for you and your students?

You will probably face some challenges as you shift to using model-based inquiry, and you may want to think about how to overcome them. Maybe time is an issue. For example, you may need more time for your own learning to better understand the modeling practice before you try to implement it in your classroom with your students. It's okay to take that time. You can tap into many online and print resources. However, keep in mind that you don't need to be an expert to start with something small. The systems model workshop I facilitated didn't take much time to plan or implement.

You may think that you don't have enough time for your students to practice modeling because there is pressure to cover a large amount of material. Consider focusing on the most important science ideas your students need to know, and let go of those that would be nice for them to know, but are not essential. Try using models to monitor your students' ideas, and encourage them to revise their models as their thinking changes throughout a unit.

Perhaps the curricular materials you use aren't written from a modeling perspective, and you need to adjust them accordingly. Insert modeling into what you are already doing to make it a richer experience for your students. Even making one whole-class model is better than doing nothing at all.

Maybe you're unsure of how to effectively support your students in developing and critiquing ideas as they incorporate modeling into their learning. It takes practice to learn a new teaching strategy. Understanding and being upfront about your challenges can help you surmount them and tap into the educational benefits to be gained from using models.

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## Conclusion

**R**emember, you don't need to do everything yourself. Parents and other caregivers play a critical role in encouraging and supporting their children's science learning at home, in school, and throughout their communities. Parents are valuable partners in cultivating science learning confidence and skills. Because models are commonly experienced by everyone in their lives, parents can foster the use of models outside of school through authentic tasks like cooking, planning a trip, and other everyday activities. You must work with them to make connections.

If you do incorporate models in your instruction, it is likely your students will think more critically and learn more deeply. It is also likely that they will have the bonus of learning social skills as they adhere to norms established for working together to make sense of the science they are learning in your classroom. Using models will help shape a richer learning experience for your students and can help them understand the real-world applications of science.

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