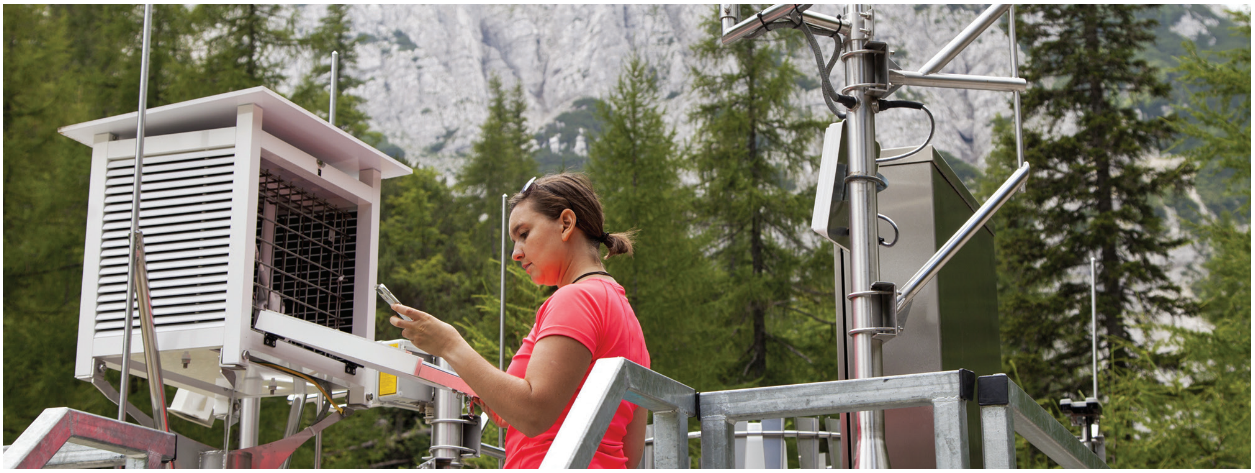
Models: Bringing Real-World Phenomena to School

Whether learning in a physical or virtual classroom, using models helps students understand real-world phenomena—like COVID-19—and solve problems related to phenomena.

"Thanks in large part to the power of model-based science, we are in a far better place than any generation before us to deal successfully and efficiently with a pandemic of this scale." That statement about the COVID-19 pandemic is from Rachael L. Brown, director of the Centre for Philosophy of the Sciences, Australian National University (Brown 2020). It highlights the value of scientific modeling in making complex issues that impact the world easier to understand—to define, quantify, and visualize.

Modeling is a key process for *both* scientists and engineers. Models represent a system (or parts of a system) and its interactions—such as inputs, processes, and outputs—and can be modified or refined with new evidence or new test results.

- Scientists use models to help develop questions and explanations, generate data that can be used to make predictions, and communicate ideas to others (NSTA 2014).
- Engineers use models to help analyze a system to see where or under what conditions flaws might develop or to test possible solutions to a program (NSTA 2014).



A meteorologist gathers data at an observation station.

For example, an epidemiology-driven machine-learning model is just one of the models developed to predict the spread of COVID-19 (UCLA Samueli Newsroom 2020). In atmospheric science, forecast models use equations and weather data to guide meteorologists in predicting the weather (NOAA 2017). In earth science, soil scientists use stream tables (or river models) to study erosion. In mechanical engineering, engineers use computational models of wind turbines to visualize and refine a design and communicate the design to others.

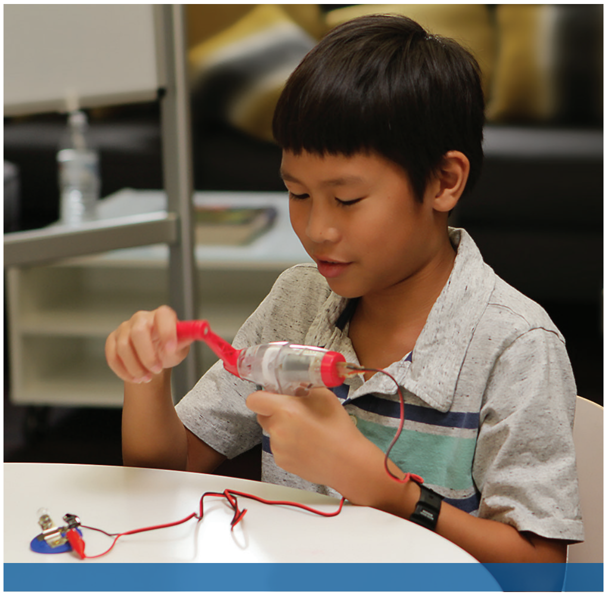
In science education, in which both science and engineering practices are taught, models are powerful tools that engage students by combining physical, tactile learning reinforced with digital content to construct knowledge. Science standards based in phenomena (including problems that arise from phenomena) and three-dimensional learning, such as the Next Generation Science Standards* (NGSS), incorporate modeling, encouraging students to learn by following the same science and engineering practices that scientists and engineers do.

"One of the best ways to become comfortable with the changing state of the world is by arming yourself with knowledge and then using that knowledge to make a difference in the world. This is true for young people as well," Smithsonian Science Education Center Director Dr. Carol O'Donnell writes (Smithsonian Institution 2020). She explains that as students engage in activities—including creating models—they are better equipped to share their knowledge, engineer solutions to problems that arise from phenomena, and take action.

The Progression of Modeling

"Models make it possible to go beyond observables and imagine a world not yet seen." So says the National Academies of Sciences, Engineering, and Medicine [formerly the National Research Council (NRC)], noting that modeling in science education should begin in the earliest grades and progress to more abstract representations for students as their learning evolves (NRC 2012, 50, 58). However, with newer standards, there has been a shift in when models are introduced in the lessons.

"Historically, we would start with a model and have students 'do' an experiment that we predetermined, and then we would ask students to apply their findings to something real," O'Donnell explains. "Today, it's the reverse. You start with the real-world scientific phenomenon or problem, you engage students in sensemaking—the idea of what you notice about the phenomenon or problem and what you wonder—and *that* drives the need to engage with a model to explain the questions that may have arisen from the students' observation of the phenomenon or problem."



By beginning with asking questions and wondering about phenomena or problems that arise from phenomena, science and engineering are put into a broader context, which cognitive psychologists say helps enhance students' memory of the experience (Godden and Baddeley 1975). "In particular, experiences which involve engaging our perceptions of sight, sound, touch, smell, or taste, coupled with strong and realistic context, stimulate a pattern of neural activity in our brains that help us remember the experiences with greater detail," O'Donnell says (O'Donnell 2019). In other words, the hands-on, multisensory nature of phenomenon-driven learning and use of modeling can be considered an essential ingredient of the glue that helps learning stick.

In *A Framework for K–12 Science Education,* the focus is on conceptual models—explicit representations that "allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem" (NRC 2012, 56). These include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Developing conceptual models engages students as they're motivated to figure out why something happens.

- Through observations, testing, and refining, they use scientific models to explain phenomena and predict what may happen.
- To incorporate engineering practices, they create and use models to test solutions.

Throughout the process, students continue to deepen understanding as they mimic how scientists and engineers develop explanations, make predictions, and solve problems.

> "Models make it possible to go beyond observables and imagine a world not yet seen."
>
> **—NRC *Framework* 2012, 50**

Model Growth by Grade Level

The NGSS outlines a logical progression of developing and using models in education (NGSS Lead States 2013, 6).

- Grades K–2: Builds on prior experiences and progresses to include using and developing models—such as diagrams, drawings, physical replicas, dioramas, dramatizations, and storyboards—that represent concrete events or design solutions.
- Grades 3–5: Builds on K–2 experiences and progresses to build and revise simple models and using models to represent events and design solutions.
- Grades 6–8: Builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.
- Grades 9–12: Builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

Why is my shadow shorter sometimes and longer other times?

Credit: Smithsonian Science Education Center

What Makes a Good Model?

No matter what type of model students use to explain a phenomenon, solve a problem, or make a prediction, the models should incorporate prior experiences to build toward answering a question or solving a problem about a phenomenon. Ideally, the question or problem should promote a transdisciplinary approach, integrating science content across a variety of subjects—such as literacy, history, art, and culture—giving the phenomena being investigated a real-world perspective. This can help students understand which features are important and how they interact, enabling them to not only develop explanations but also to use what they observe to make predictions.

As part of the process, students should acknowledge that their models are limited by the data known and be prepared to refine as new data becomes available. For example, in discussing pandemic models, scientists for the National Institute of Allergy and Infectious Diseases look at the data as it's evolving and do everything they can to ignore extremes of the model. Atmospheric scientists who use computer models to forecast the path of a hurricane may have 20–30 different models that all differ slightly, so they need to examine trends. Soil scientists may need to simulate river flows in a variety of conditions to model real-world processes. Mechanical engineers may need to refine their models to better harness wind energy.

O'Donnell says one example of a K–5 activity at ssec.si.edu/distancelearning that optimizes student learning by effectively incorporating modeling looks at shadows to examine the scientific phenomenon of the Sun's apparent daily motion across the sky. Designed for grades K–3 students, the lesson builds toward answering an essential question: "Why is my shadow shorter sometimes and longer other times?"

Learning remotely with video support or in a classroom, students draw on prior experiences and share their ideas about the question, make and record observations, develop a model that will help them figure out the answer to the question, check the accuracy of their model through further observation, and make predictions.

What makes the activity an effective learning experience? O'Donnell summarizes: "It's phenomenon driven, it creates a model to explain that phenomenon, and students engage in sensemaking and questioning, then revisit to understand that model."

To assess students' models, consider these points:

- Is the model based on reliable observations?
- Does it aid in sensemaking?
- Does it explain the characteristics of the observations used to formulate it?
- Is it predictive?
- Does it answer an essential question about a phenomenon or help students solve a problem?
- Can it be refined when new data is determined?

Students make maps and create legends to model what maps can tell us about land and water on Earth.

Modeling for the Real World

From the first months of the COVID-19 pandemic, phrases such as "flatten the curve" became a routine part of even casual conversations as the world population became invested in the science, evaluating epidemiology-driven models to make predictions and decisions that affected every aspect of society.

To prepare students for understanding phenomena they encounter, look for real-world current events that are examples of scientific modeling (e.g., predicting the spread of a pandemic, studying the path of a hurricane, reducing soil erosion on a hillside, or designing a wind turbine to harness wind energy). Create transdisciplinary science lessons that embed a universal perspective by incorporating a cultural view and ample opportunity to converge the history, art, and science of phenomena together. Lessons should engage even the youngest students in thinking critically as they seek to answer essential questions, creating a bank of prior knowledge that can be refined and applied to new and evolving situations.

An understanding of modeling not only provides a basis for students interested in future science technology, engineering, and math (STEM) careers but empowers all learners to be global citizens who are critical thinkers as they navigate phenomena in the world around them.

Models That Work for Classroom and Distance Learning

Grade	Essential Question	Model
1	How can we send a message using sound?	Students design a code (depicted as a series of dots and dashes) using patterns of sound and devise ways to represent their patterns.
2	How can we stop soil from washing away?	Students investigate how different materials might slow down erosion using models to represent the real materials.
3	How can we protect animals when their habitats change?	Students play the roles of tigers and plants and use a model of a tiger habitat (denoted by chart paper) to explain why tiger populations are declining.
4	How does motion energy change in a collision?	Students design a model of a bicycle helmet that changes motion energy to heat, testing it using an egg to represent a head.
5	How can we identify materials based on their properties?	Students watch a computer simulation of sugar dissolving in water and water evaporating, discovering that water and sugar comprise particles that are too small to be seen.

*Examples are from Smithsonian Science for the Classroom™.

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How the Smithsonian Science Education Center Supports Using Models in Three-Dimensional Learning

The Smithsonian Science Education Center has developed Smithsonian Science for the Classroom™ for grades 1–5 and Science and Technology Concepts™ Middle School curricula from the ground up to engage students. Every module is three-dimensional, hands-on learning that incorporates science and engineering practices—including the modeling that helps students explain phenomena and engineer solutions to problems.

Each module offers opportunities to do science following a coherent progression as it integrates engineering concepts, literacy, and math, developing deep connections to phenomena. With print, digital, and lab materials in one all-inclusive package, the lessons are designed for classroom use but can be adapted to supplement distance learning. The accompanying literacy series, Smithsonian Science Stories, provides students with the opportunity to connect STEM to history, art, and culture at the point of use. The curricula help students realize how modeling can enhance understanding of real-world phenomena, improving the lives of all.

The Smithsonian Science Education Center also offers free STEM resources to support distance learning for grades K–8 at ssec.si.edu/distancelearning. Its most recently released resource is *COVID-19! How Can I Protect Myself and Others?* This free guide for youth helps students ages 8–17 understand the science (and social science) of the virus that causes COVID-19. Find it at ssec.si.edu/covid-19.

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