

## Practice 2 Developing and Using Models

*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 in later grades, such as a diagram representing forces on a particular object in a system. (NRC Framework, 2012, p. 58)*

Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations.

In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based upon evidence. When new evidence is uncovered that the models can’t explain, models are modified.

In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design’s features to others, and as prototypes for testing design performance.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
<p>Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.</p> <ul style="list-style-type: none"> <li>• Distinguish between a model and the actual object, process, and/or events the model represents.</li> <li>• Compare models to identify common features and differences.</li> <li>• Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s).</li> <li>• Develop a simple model based on evidence to represent a proposed object or tool.</li> </ul>	<p>Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.</p> <ul style="list-style-type: none"> <li>• Identify limitations of models.</li> <li>• Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.</li> <li>• Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution.</li> <li>• Develop and/or use models to describe and/or predict phenomena.</li> <li>• Develop a diagram or simple physical prototype to convey a proposed object, tool, or process.</li> <li>• Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.</li> </ul>	<p>Modeling in 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.</p> <ul style="list-style-type: none"> <li>• Evaluate limitations of a model for a proposed object or tool.</li> <li>• Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed.</li> <li>• Use and/or develop a model of simple systems with uncertain and less predictable factors.</li> <li>• Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.</li> <li>• Develop and/or use a model to predict and/or describe phenomena.</li> <li>• Develop a model to describe unobservable mechanisms.</li> <li>• Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.</li> </ul>	<p>Modeling in 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.</p> <ul style="list-style-type: none"> <li>• Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria.</li> <li>• Design a test of a model to ascertain its reliability.</li> <li>• Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.</li> <li>• Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.</li> <li>• Develop a complex model that allows for manipulation and testing of a proposed process or system.</li> <li>• Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.</li> </ul>

## Practice 5 Using Mathematics and Computational Thinking

*Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question. (NRC Framework, 2012, p. 65)*

Students are expected to use mathematics to represent physical variables and their relationships, and to make quantitative predictions. Other applications of mathematics in science and engineering include logic, geometry, and at the highest levels, calculus. Computers and digital tools can enhance the power of mathematics by automating calculations, approximating solutions to problems that cannot be calculated precisely, and analyzing large data sets available to identify meaningful patterns. Students are expected to use laboratory tools connected to computers for observing, measuring, recording, and processing data. Students are also expected to engage in computational thinking, which involves strategies for organizing and searching data, creating sequences of steps called algorithms, and using and developing new simulations of natural and designed systems. Mathematics is a tool that is key to understanding science. As such, classroom instruction must include critical skills of mathematics. The NGSS displays many of those skills through the performance expectations, but classroom instruction should enhance all of science through the use of quality mathematical and computational thinking.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
<p>Mathematical and computational thinking in K-2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world(s).</p> <ul style="list-style-type: none"> <li>Decide when to use qualitative vs. quantitative data.</li> <li>Use counting and numbers to identify and describe patterns in the natural and designed world(s).</li> <li>Describe, measure, and/or compare quantitative attributes of different objects and display the data using simple graphs.</li> <li>Use quantitative data to compare two alternative solutions to a problem.</li> </ul>	<p>Mathematical and computational thinking in 3-5 builds on K-2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions.</p> <ul style="list-style-type: none"> <li>Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success.</li> <li>Organize simple data sets to reveal patterns that suggest relationships.</li> <li>Describe, measure, estimate, and/or graph quantities (e.g., area, volume, weight, time) to address scientific and engineering questions and problems.</li> <li>Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.</li> </ul>	<p>Mathematical and computational thinking in 6-8 builds on K-5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments.</p> <ul style="list-style-type: none"> <li>Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.</li> <li>Use mathematical representations to describe and/or support scientific conclusions and design solutions.</li> <li>Create algorithms (a series of ordered steps) to solve a problem.</li> <li>Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.</li> <li>Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.</li> </ul>	<p>Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> <li>Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.</li> <li>Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.</li> <li>Apply techniques of algebra and functions to represent and solve scientific and engineering problems.</li> <li>Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model “makes sense” by comparing the outcomes with what is known about the real world.</li> <li>Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m<sup>3</sup>, acre-feet, etc.).</li> </ul>

## Practice 6 Constructing Explanations and Designing Solutions

The goal of science is to construct explanations for the causes of phenomena. Students are expected to construct their own explanations, as well as apply standard explanations they learn about from their teachers or reading. The *Framework* states the following about explanation:

*“The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.”*(NRC Framework, 2012, p. 52)

An explanation includes a claim that relates how a variable or variables relate to another variable or a set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design investigations to generate data.

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing, and improving solutions. This practice is described in the *Framework* as follows.

*Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.*

*In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers’ activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.* (NRC Framework, 2012, p. 68-69)

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
<p>Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.</p> <ul style="list-style-type: none"> <li>• Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena.</li> <li>• Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem.</li> <li>• Generate and/or compare multiple solutions to a problem.</li> </ul>	<p>Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.</p> <ul style="list-style-type: none"> <li>• Construct an explanation of observed relationships (e.g., the distribution of plants in the back yard).</li> <li>• Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.</li> <li>• Identify the evidence that construct or support points in an explanation.</li> <li>• Apply scientific ideas to solve design problems.</li> <li>• Generate and compare multiple solutions to a problem based on how</li> </ul>	<p>Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> <li>• Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.</li> <li>• Construct an explanation using models or representations.</li> <li>• Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.</li> <li>• Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.</li> <li>• Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.</li> </ul>	<p>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> <li>• Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.</li> <li>• Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.</li> <li>• Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.</li> <li>• Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.</li> </ul>

	<p>well they meet the criteria and constraints of the design solution.</p>	<ul style="list-style-type: none"> <li>• Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.</li> <li>• Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.</li> <li>• Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.</li> </ul>	<ul style="list-style-type: none"> <li>• Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li> </ul>
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