

Asking Questions and Defining Problems

Summary: Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution ([NRC Framework 2012, p. 56](#)). Video summarizing [Asking Questions and Defining Problems](#).

Elements of Asking Questions and Defining Problems:

- ✓ Ask questions
 - that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
 - that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
 - to determine relationships, including quantitative relationships, between independent and dependent variables.
 - to clarify and refine a model, an explanation, or an engineering problem.
- ✓ Evaluate a question to determine if it is testable and relevant.
- ✓ Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory.
- ✓ Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
- ✓ Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environment.

Developing and Using Models

Summary: 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](#)). Video summarizing [Developing and Using Models](#).

Elements of Developing and Using Models:

- ✓ 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.
- ✓ Design a test of a model to ascertain its reliability.
- ✓ 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.
- ✓ 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.
- ✓ Develop a complex model that allows for manipulation and testing of a proposed process or system.
- ✓ Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Planning and Carrying Out Investigations

Summary: Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students’ own questions ([NRC Framework, 2012, p. 61](#)). Video summarizing [Developing and Using Models](#).

Elements of Planning and Carrying Out Investigations:

- ✓ Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation’s design to ensure variables are controlled.
- ✓ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- ✓ Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
- ✓ Select appropriate tools to collect, record, analyze, and evaluate data.
- ✓ Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated.
- ✓ Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

Analyzing and Interpreting Data

Summary: Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.

Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures ([NRC Framework, 2012, p. 61-62](#)). Video summarizing [Analyzing and Interpreting Data](#).

Elements of Analyzing and Interpreting Data:

- ✓ Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
- ✓ Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
- ✓ Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
- ✓ Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

Using Mathematics and Computational Thinking

Summary: 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](#)). Video summarizing [Using Mathematics and Computational Thinking](#).

Elements of Using Mathematics and Computational Thinking:

- ✓ Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
- ✓ Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
- ✓ Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
- ✓ 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.
- ✓ 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/m³, acre-feet, etc.).

Note, the mathematics that students should be using in high school science courses is based on the [New Jersey Student Learning Standards for Mathematics](#). Also, please note that [Advance Placement](#) science courses limit the mathematical expectations to Algebra I and Algebra II.

Constructing explanations (for science) and designing solutions (for engineering)

Summary: “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). Video summary of [Constructing Explanations and Designing Solutions](#).

Elements of Constructing explanations (for science) and designing solutions (for engineering)

- ✓ Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
- ✓ 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.
- ✓ Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
- ✓ 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.
- ✓ 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.

Science and the Engineering Practices Grades 9-12 Quick Reference

Engaging in Argument from Evidence

Summary: The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose. ([NRC Framework, 2012, p. 73](#)). Video summary of [Engaging in Argument from Evidence](#).

Elements of Engaging in Argument from Evidence:

- ✓ Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
- ✓ Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
- ✓ Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions.
- ✓ Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
- ✓ Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
- ✓ Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

Obtaining, Evaluating, and Communicating Information

Summary: Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering ([NRC Framework, 2012, p. 76](#)). Video summary of [Obtaining, Evaluating, and Communicating Information](#).

Elements of Obtaining, Evaluating, and Communicating Information:

- ✓ Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- ✓ Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.
- ✓ Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.
- ✓ Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible.
- ✓ Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, and/or mathematically).