Appendix F – Science and Engineering Practices in the NGSS

A Science Framework for K-12 Science Education provides the blueprint for developing the *Next Generation Science Standards* (NGSS). The *Framework* expresses a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. As can be expected, the *Framework* identified a small number of disciplinary core ideas that all students should learn with increasing depth and sophistication, from Kindergarten through grade twelve. Key to the vision expressed in the *Framework* is for students to learn these disciplinary core ideas in the context of science and engineering practices. The importance of combining science and engineering practices and disciplinary core ideas is stated in the *Framework* as follows:

> *Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content.* (NRC *Framework*, 2012, p. 218)

The *Framework* specifies that each performance expectation must combine a relevant practice of science or engineering, and a core disciplinary idea, appropriate for students of the designated grade level. That guideline is perhaps the most significant way in which the NGSS differs from prior standards documents. In the future, science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. They will be assessed together, showing that students not only "know" science concepts; but also that they can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design. The *Framework* uses the term "practices," rather than "science processes" or "inquiry" skills for a specific reason:

> *We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice.* (NRC *Framework,* 2012, p. 30)

The eight practices of science and engineering that the *Framework* identifies as essential for all students to learn, and describes in some detail, are listed below:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Rationale

Chapter 3 of the *Framework* describes each of the eight practices of science and engineering and presents the following rationale for why they are essential.

> *Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.*
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> *The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in. Students may then recognize that science and engineering can contribute to meeting many of the major challenges that confront society today, such as generating sufficient energy, preventing and treating disease, maintaining supplies of fresh water and food, and addressing climate change.*
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> *Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering.* (NRC *Framework* 2012, pp. 42-43)

As suggested in the rationale, above, Chapter 3 derives the eight practices based on an analysis of what professional scientists and engineers do. We recommend that users of the NGSS read that chapter carefully, as it provides valuable insights into the nature of science and engineering, as well as the connections between these two closely allied fields. The intent of the present chapter is more limited—to describe what each of these eight practices implies about what students can do. Its purpose is to enable readers to better understand the performance expectations, which is something that we had to do in order to write performance expectations. Consequently, it will show the development of what we call the "Practices Matrix," which lists the specific capabilities included in each practice for each grade band (K-2, 3-5, 6-8, 9-12).

Guiding Principles

Before describing the capabilities associated with each of the eight practices, we will share the insights we've gained in the process of using the eight practices to craft the standards and explain them to others. These insights have gained the status of "guiding principles" that helped us to craft the performance expectations that serve as building blocks of the standards. We are indebted to the state teams and thousands of other individuals who have asked hard questions, and helped us better understand what it means to combine practices of science and engineering with the core disciplines of science.

> **Students in grades K-12 should engage in all of the eight practices over each grade band.** All eight practices are accessible at some level to the youngest children, and students' abilities to use the practices are expected to grow annually. However, the NGSS only identifies the capabilities that students are expected to acquire by the end of the grade band. That is, by grade 2, 5, 8, and 12. Curriculum developers and teachers will need to determine how best to help students advance in their capabilities to use the practices within the grade bands.
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> **Practices grow in complexity and sophistication across the grades.** The *Framework* suggests how students' capabilities to use each of the practices should progress as they mature and engage in science learning. For example, the practice of "planning and carrying out investigations" would begin at the kindergarten level with well-structured situations in which students have assistance in identifying phenomena to be investigated, and how to observe, measure, and record outcomes.

By upper elementary school students should be able to plan their own investigations. The nature of investigations that students should be able to plan and carry out is also expected to increase as students mature, including the complexity of questions to be studied, the ability to determine what kind of investigation is needed to answer different kinds of questions, whether or not variables need to be controlled and if so which are most important, and at the high school level, how to take measurement error into account. As listed in the tables in this chapter, each of the eight practices has its own progression, from kindergarten to grade 12. While these progressions are derived from Chapter 3 of the *Framework*, they are refined based on our experience in crafting the NGSS and feedback that we've received from reviewers.

Each practice may reflect science or engineering. Each of the eight practices can be used in the service of science inquiry or engineering design. The best way to tell if a practice is being used for science or engineering is to ask about the goal of the activity. Is it to answer a question? In which case, they are doing science. Is the purpose to define and solve a problem? In which case, they are doing engineering. Box 3-2 on pages 50-53 of the *Framework* provides a side-by-side comparison of how scientists and engineers use these practices. This chapter briefly summarizes what it "looks like" for a student to use each practice for science or for engineering.

Practices represent what students are expected to do, and are not teaching methods or curriculum. The *Framework* occasionally offers suggestions for instruction, such as how a science unit might begin with a scientific investigation, which then leads to the solution of an engineering problem. In the NGSS we have attempted to avoid such suggestions since our goal is to describe, as clearly as possible, what students are able to do, rather than how they should be taught. It has been suggested, for example, that the NGSS recommend certain teaching strategies such as biomimicry—the application of biological features to solving engineering design problems. Although instructional units that make use of biomimicry seem well-aligned with the spirit of the *Framework* to encourage integration of core ideas and practices, we judge biomimicry and similar teaching approaches to be more closely related to curriculum and instruction than to assessment. So we have decided not to include them in the NGSS.

The eight practices are not separate; they intentionally overlap and interconnect. As explained by Bell et al. (2012), the eight practices do not operate in isolation. Rather, they tend to unfold sequentially, and even overlap. For example, the practice of "asking questions" may lead to the practice of "modeling" or "planning and carrying out an investigation," which in turn may lead to "analyzing and interpreting data." The practice of "mathematical and computation thinking" includes some of the practices in "analyzing and interpreting data." So, just as it is important for students to be able to carry out each of the individual practices, it is important for them to see the connections among the eight practices.

Performance expectations focus on some but not all capabilities associated with a practice. The *Framework* identifies a number of features or components of each practice. The practices matrix, which is described in this chapter, lists all of the components of each practice as a bulleted list within each grade band. As we developed performance expectations it became clear that it's too much to expect each performance to reflect all components of a given practice. Consequently, where we illustrate the connections between performance expectations and practices, we point out which aspects of the practice are reflected in the performance expectation.

On the following pages we briefly describe each of the eight practices. Each discussion ends with a table illustrating the components of the practice that students are expected to master at the end of each grade band. All eight tables comprise what we have been calling the *practices matrix*. During development of the NGSS we have revised the practices matrix more than once to reflect our improved understanding of how the practices connect with the disciplinary core ideas, and in response to our many reviewers. The practices matrix has been invaluable in developing the performance expectations that serve as building blocks of the standards.

Practice 1 Asking Questions and Defining Problems

> *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)

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world, inspired by the predictions of a model or theory, or they can be stimulated by the need to solve a problem. What distinguishes scientific questions from other types of questions is that they can be answered by appealing to evidence, including evidence that has been gathered by others, or that might be gathered by planning and conducting an investigation.

While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are the possible trade-offs? What evidence do we need to determine which solution is best?

Whether engaged in science or engineering, the ability to ask good questions and clearly define problems is essential for everyone. The following progression of Practice 1 competencies summarizes what students should be able to do by the end of each grade band.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Asking questions and defining problems in grades K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. • Ask questions based on observations of the natural and/or designed world. • Define a simple problem that can be solved through the development of a new or improved object or tool.	Asking questions and defining problems in grades 3–5 builds from grades K–2 experiences and progresses to specifying qualitative relationships. • Identify scientific (testable) and non-scientific (non-testable) questions. (4th Grade) • Ask questions based on careful observations of phenomena and information. • Ask questions to clarify ideas or request evidence. • Ask questions that relate one variable to another variable. • Ask questions to clarify the constraints of solutions to a problem. • Use prior knowledge to describe problems that can to be solved. • Define a simple design problem that can be solved through the development of an object, tool or process and includes several criteria for success and constraints on materials, time, or cost. • Formulate questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.	Asking questions and defining problems in grades 6–8 builds from grades K–5 experiences and progresses to formulating and refining empirically testable models to explain phenomena or solve problems. • Ask questions that arise from careful observation of phenomena, models, or unexpected results. • Ask questions to clarify or identify evidence and the premise(s) of an argument. • Ask questions to determine relationships between independent and dependent variables. • Ask questions that challenge the interpretation of a data set. • Ask questions to clarify and refine a model, an explanation, or an engineering problem. • Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. • Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (a possible explanation that predicts a particular and stable outcome) based on a model or theory.	Asking questions and defining problems in grades 9–12 builds from grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design solutions using models and simulations. • Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. • Ask questions that require relevant empirical evidence to answer. • Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. • Ask and evaluate questions that challenge the premise 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 environmental considerations.

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 they do not correspond exactly to the real world, they do 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, 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.

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
Modeling in K–2 builds on prior experiences and progresses to include identifying, using, and developing models that represent concrete events or design solutions. • Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences. • Develop and/or use models (i.e., diagrams, drawings, physical replicas, dioramas, dramatizations, or storyboards) that represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed worlds. • Develop a simple model that represents a proposed object or tool.	Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions. • Develop and revise models collaboratively to measure and explain frequent and regular events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Use simple models to describe or support explanations for phenomena and test cause and effect relationships or interactions concerning the functioning of a natural or designed system. • Identify limitations of models. • Develop a diagram or simple physical prototype to convey a proposed object, tool or process. • Use a simple model to test cause and effect relationships concerning the functioning of a proposed object, tool or process.	Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to support explanations, describe, test, and predict more abstract phenomena and design systems. • Use and/or develop models to predict, describe, support explanations, and/or collect data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales. • Develop models to describe unobservable mechanisms. • Modify models—based on their limitations—to increase detail or clarity, or to explore what will happen if a component is changed. • Use and develop models of simple systems with uncertain and less predictable factors. • Develop a model that allows for manipulation and testing of a proposed object, tool, process or system. • Evaluate limitations of a model for a proposed object or tool.	Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world. • Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. • Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. • Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. • Design a test of a model to ascertain its reliability. • Develop a complex model that allows for manipulation and testing of a proposed process or system. • Evaluate merits and limitations of two different models of the same proposed tool, process, or system in order to select or revise a model that best fits the evidence or design criteria.

Practice 3 Planning and Carrying Out Investigations

> *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)

Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model for how the world works. The purpose of engineering investigations might be to find out how to fix or improve the functioning of a technological system or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation and to plan a course of action that will provide the best evidence to support their conclusions.

Over time students are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables are to be treated as results or outputs, which are to be treated as inputs and intentionally varied from trial to trial, and which are to be controlled, or kept the same across trials. In the case of field observations planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations may include elements of all of the other practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. • With guidance, design and conduct investigations in collaboration with peers. (for K) • Design and conduct investigations collaboratively. • Evaluate different ways of observing and/or measuring an attribute of interest. • Make direct or indirect observations and/or measurements to collect data which can be used to make comparisons. • Identify questions and make predictions based on prior experiences. • Make direct or indirect observations and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5builds on K–2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. • Design and conduct investigations collaboratively, using fair tests in which variables are controlled and the number of trials considered. • Evaluate appropriate methods and tools for collecting data. • Make observations and/or measurements, collect appropriate data, and identify patterns that provide evidence for an explanation of a phenomenon or test a design solution. • Make measurements of two different models of the same proposed object, tool or process to determine which better meets criteria for success.	Planning and carrying out investigations progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions. • Conduct an investigation and evaluate and revise the experimental design to ensure that the data generated can meet the goals of the experiment. • Design an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support their claim. • Evaluate the accuracy of various methods for collecting data. • Collect data and generate evidence to answer scientific questions or test design solutions under a range of conditions. • Collect data about the performance of a proposed object, tool, process or system under a range of conditions.	Planning and carrying out investigations progresses to include investigations that build, test, and revise conceptual, mathematical, physical, and empirical models. • Design an investigation individually and collaboratively and test designs 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. • Design and conduct an investigation individually and collaboratively, 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. • Select appropriate tools to collect, record, analyze, and evaluate data. • Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts. • 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. • Use investigations to gather evidence to support explanations or concepts.

Practice 4 Analyzing and Interpreting Data

> *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.*
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> *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)

As students mature they are expected to expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students are also expected to improve their abilities to interpret data by identifying significant features and patterns, use mathematics to represent relationships between variables, and take into account sources of error. Whether analyzing data for the purpose of science or engineering, it is important that students present the data so that it serves as evidence to support their conclusions.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Analyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations. • Use and share pictures, drawings, and/or writings of observations. • Use observations to describe patterns and/or relationships in the natural and designed worlds in order to answer scientific questions and solve problems. • Make measurements of length to quantify data. • Analyze data from tests of an object or tool to determine if a proposed object or tool functions as intended.	Analyzing data in 3–5 builds on K–2 and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. • Display data in tables and graphs, using digital tools when feasible, to reveal patterns that indicate relationships. • Use data to evaluate claims about cause and effect. • Compare data collected by different groups in order to discuss similarities and differences in their findings. • Use data to evaluate and refine design solutions. • Interpret data to make sense of and explain phenomena, using logical reasoning, mathematics, and/or computation • Analyze data to refine a problem statement or the design of a proposed object, tool or process.	Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible. • Construct, analyze, and interpret graphical displays of data to identify linear and nonlinear relationships. • Consider limitations of data analysis (e.g., measurement error), and seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials). • Analyze and interpret data in order to determine similarities and differences in findings. • Distinguish between causal and correlational relationships. • Use graphical displays (e.g., maps) of large data sets to identify temporal and spatial relationships. • Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria for success.	Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. • Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. • 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. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • 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. • Evaluate the impact of new data on a working explanation of a proposed process or system.

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 can enhance the power of mathematics by automating calculations, approximating solutions to problems that cannot be calculated precisely, and analyzing large data sets available on the Internet 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 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
Mathematical and computational thinking at the K–2 level builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world. • Decide when to use qualitative vs. quantitative data. • Use counting and numbers to identify and describe patterns in the natural and designed worlds. • Describe, measure, and compare quantitative attributes of different objects and display the data using simple graphs. • Use quantitative data to compare two alternative solutions to a problem.	Mathematical and computational thinking at the 3–5 level builds on K–2 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. • Use mathematical thinking and/or computational outcomes to compare alternative solutions to an engineering problem. • Organize simple data sets to reveal patterns that suggest relationships. • Describe, measure, estimate, and graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems. • Decide if qualitative or quantitative data is best to determine whether a proposed object or tool meets criteria for success.	Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. • Create algorithms (a series of ordered steps) to solve a problem. • Apply concepts of ratio, rate, percent, basic operations, and simple algebra to scientific and engineering questions and problems. • Use mathematical arguments to describe and support scientific conclusions and design solutions. • Use digital tools, mathematical concepts, and arguments to test and compare proposed solutions to an engineering design problem.	Mathematical and computational thinking 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. • Use mathematical or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. • 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. • Create a simple computational model or simulation of a designed device, process, or system.

Practice 6 Constructing Explanations and Designing Solutions

The goal of science is to explain phenomena. As a practice, students are expected to construct their own explanations as well as apply standard explanations that they learn about from their teachers or reading. The goal of engineering is to solve problems. As a practice designing solutions to problems is a systematic process that involves defining the problem, then generating, testing and improving solutions. These practices are described in the *Framework* as follows.

> *Engaging students with standard scientific explanations of the world— helping them to gain an understanding of the major ideas that science has developed— is a central aspect of science education. 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.*
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> *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
Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence or ideas in constructing explanations and designing solutions. • Use information from direct or indirect observations to construct explanations. • Use tools and materials provided to design a device or solution to a specific problem. • Distinguish between opinions and evidence in one's own explanations. • Generate and compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on prior experiences in K–2 and progresses to the use of evidence in constructing multiple explanations and designing multiple solutions. • Construct explanations of observed quantitative relationships (e.g., the distribution of plants in the back yard). • Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation. • Apply scientific knowledge to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the problem.	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 knowledge, principles, and theories. • Construct explanations for either qualitative or quantitative relationships between variables. • Apply scientific reasoning to show why the data are adequate for the explanation or conclusion. • Base explanations on evidence obtained from sources (including their own experiments) and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. • Undertake design projects, engaging in the design cycle, to construct and implement a solution that meets specific design criteria and constraints. • Apply scientific knowledge and evidence to explain real-world phenomena, examples, or events. • Construct explanations from models or representations. • Apply scientific knowledge to design, construct, and test a design of an object, tool, process or system. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	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 knowledge, principles, and theories. • Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. • Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. • Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. • Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. • Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Practice 7 Engaging in Argument from Evidence

> *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)

Argumentation is a process for reaching explanations and finding solutions. In science, reasoning and argument based on evidence are essential in identifying the best explanation for a natural phenomenon. In engineering, reasoning and argument are needed to identify the best solution to a design problem. Student engagement in scientific argumentation is critical if students are to understand the culture in which scientists live, and how to apply science and engineering for the benefit of society.

Whether investigating a phenomenon or testing a design, students are expected to use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to identify strengths and weaknesses of claims.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Engaging in argument from evidence in K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed world. • Identify arguments that are supported by evidence. • Listen actively to others' explanations and arguments and ask questions for clarification. • Make a claim about the effectiveness of an object, tool, or solution that is based on relevant evidence.	Engaging in argument from evidence in 3–5 builds from K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world. • Construct and/or support scientific arguments with evidence, data, and/or a model. • Compare and refine arguments based on the strengths and weaknesses of the evidence presented. • Respectfully provide and receive critiques on scientific arguments with peers by citing relevant evidence and posing specific questions. • Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.	Engaging in argument from evidence in 6–8 builds from K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. • Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation for a phenomenon or a solution to a problem. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. • Respectfully provide and receive critiques on scientific arguments by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • Compare two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system, based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.	Engaging in argument from evidence in 9–12 builds from K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world. Arguments may also come from current scientific or historical episodes in science. • Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. • Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Construct a counter-argument that is based on data and evidence that challenges another proposed argument. • Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. • Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

Practice 8 Obtaining, Evaluating, and Communicating Information

> *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)

Being able to read, interpret and produce scientific and technical text are fundamental practices of science and engineering, as is the ability to communicate clearly and persuasively. Being a critical consumer of information about science and engineering requires the ability to read or view reports of scientific or technological advances or applications, whether found in the press, the Internet, or in a town meeting, and to recognize the salient ideas, identify sources of error and methodological flaws, distinguish observations from inferences, arguments from explanations and claims from evidence. Scientists and engineers employ multiple sources to acquire information that is used to evaluate the merit and validity of claims, methods, and designs. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information. • Read and comprehend grade-appropriate texts and media to acquire scientific and/or technical information. • Critique and/or communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers. • Record observations, thoughts, and ideas. • Explain how specific images (e.g., a diagram showing how a machine works) contribute to and clarify a text. • Obtain information by using various text features (e.g., headings, tables of contents, glossaries, electronic menus, icons).	Obtaining, evaluating, and communicating information in 3–5 builds on K–2 and progresses to evaluating the merit and accuracy of ideas and methods. • Compare and/or combine across complex texts and/or other reliable media to acquire appropriate scientific and/or technical information. • Determine the main idea of a scientific text and explain how it is supported by key details; summarize the text. • Combine information in written text with that contained in corresponding tables, diagrams, and/or charts. • Use multiple sources to generate and communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. • Use models to share findings or solutions in oral and/or written presentations, and/or extended discussions. • Obtain and combine information from books and/or other reliable media about potential solutions to a specific design problem.	Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods. • Communicate scientific information and/or technical information (e.g. about a proposed object, tool, process, system) in different formats (e.g., verbally, graphically, textually, and mathematically). • Gather, read, and communicate information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used. • Read critically using scientific knowledge and reasoning to evaluate data, hypotheses, conclusions that appear in scientific and technical texts in light of competing information or accounts; provide an accurate summary of the text distinct from prior knowledge or opinions. • Critically evaluate whether or not technical information on a device, tool or process is relevant to its suitability to solve a specific design problem.	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. • Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. • Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. • Compare, integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) in order to address a scientific question or solve a problem.

Reflecting on the practices of science and engineering

Engaging students in the practices of science and engineering outlined in this chapter is not sufficient for science literacy. It is also important for students to stand back and reflect on how these practices have contributed to their own development, and to the accumulation of scientific knowledge and engineering accomplishments over the ages. How to accomplish this is a matter for curriculum and instruction, rather than for standards, so no specific guidelines are provided in this document. Nonetheless, this chapter would not be complete without an acknowledgment that reflection is essential if students are to become aware of themselves as competent and confident learners and doers in the realms of science and engineering.

References

Bell, P., Bricker, L., Tzou, Carrie, Lee., T., and Van Horne, K. (2012). Exploring the science framework; Engaging learners in science practices related to obtaining, evaluating, and communicating information. *Science Scope*, 36(3), 18-22.

NGSS Science and Engineering Practices* (January 2013 Draft)

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Asking Questions and Defining Problems A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world. Both scientists and engineers also ask questions to clarify ideas.	Asking questions and defining problems in grades K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. ▪ Ask questions based on observations of the natural and/or designed world. ▪ Define a simple problem that can be solved through the development of a new or improved object or tool.	Asking questions and defining problems in grades 3–5 builds from grades K–2 experiences and progresses to specifying qualitative relationships. ▪ Identify scientific (testable) and non-scientific (non-testable) questions. ▪ Ask questions based on careful observations of phenomena and information. ▪ Ask questions to clarify ideas or request evidence. ▪ Ask questions that relate one variable to another variable. ▪ Ask questions to clarify the constraints of solutions to a problem. ▪ Use prior knowledge to describe problems that can be solved. ▪ Define a simple design problem that can be solved through the development of an object, tool or process and includes several criteria for success and constraints on materials, time, or cost. ▪ Formulate questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.	Asking questions and defining problems in grades 6–8 builds from grades K–5 experiences and progresses to formulating and refining empirically testable models that support explanations of phenomena or solutions to problems. ▪ Ask questions that arise from careful observation of phenomena, models, or unexpected results. ▪ Ask questions to clarify or identify evidence and the premise(s) of an argument. ▪ Ask questions to determine relationships between independent and dependent variables. ▪ Ask questions that challenge the interpretation of a data set. ▪ Ask questions to clarify and refine a model, an explanation, or an engineering problem. ▪ Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. ▪ Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (a possible explanation that predicts a particular and stable outcome) based on a model or theory.	Asking questions and defining problems in grades 9–12 builds from grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design solutions using models and simulations. ▪ Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. ▪ Ask questions that require relevant empirical evidence to answer. ▪ Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. ▪ Ask and evaluate questions that challenge the premise 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 environmental considerations

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Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Developing and Using Models A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.	Modeling in K–2 builds on prior experiences and progresses to include identifying, using, and developing models that represent concrete events or design solutions. ▪ Distinguish between a model and the actual object, process, and/or events the model represents. ▪ Compare models to identify common features and differences. ▪ Develop and/or use models (i.e., diagrams, drawings, physical replicas, dioramas, dramatizations, or storyboards) that represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed worlds. ▪ Develop a simple model that represents a proposed object or tool.	Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions. ▪ Develop and revise models collaboratively to measure and explain frequent and regular events. ▪ Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. ▪ Use simple models to describe or support explanations for phenomena and test cause and effect relationships or interactions concerning the functioning of a natural or designed system. ▪ Identify limitations of models. ▪ Develop a diagram or simple physical prototype to convey a proposed object, tool or process. ▪ Use a simple model to test cause and effect relationships concerning the functioning of a proposed object, tool or process.	Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to support explanations, describe, test, and predict more abstract phenomena and design systems. ▪ Use and/or develop models to predict, describe, support explanations, and/or collect data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales. ▪ Develop models to describe unobservable mechanisms. ▪ Modify models—based on their limitations—to increase detail or clarity, or to explore what will happen if a component is changed. ▪ Use and develop models of simple systems with uncertain and less predictable factors. ▪ Develop a model that allows for manipulation and testing of a proposed object, tool, process or system. ▪ Evaluate limitations of a model for a proposed object or tool.	Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world. ▪ Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. ▪ Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. ▪ Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. ▪ Design a test of a model to ascertain its reliability. ▪ Develop a complex model that allows for manipulation and testing of a proposed process or system. ▪ Evaluate merits and limitations of two different models of the same proposed tool, process, or system in order to select or revise a model that best fits the evidence or design criteria.

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Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Planning and Carrying Out Investigations Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.	Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. ▪ With guidance, design and conduct investigations in collaboration with peers. ▪ Design and conduct investigations collaboratively. ▪ Evaluate different ways of observing and/or measuring an attribute of interest. ▪ Make direct or indirect observations and/or measurements to collect data, which can be used to make comparisons. ▪ Identify questions and make predictions based on prior experiences. ▪ Make direct or indirect observations and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. ▪ Design and conduct investigations collaboratively, using fair tests in which variables are controlled and the number of trials considered. ▪ Evaluate appropriate methods and tools for collecting data. ▪ Make observations and/or measurements, collect appropriate data, and identify patterns that provide evidence for an explanation of a phenomenon or test a design solution. ▪ Make measurements of two different models of the same proposed object, tool or process to determine which better meets criteria for success.	Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. ▪ Conduct an investigation and evaluate and revise the experimental design to ensure that the data generated can meet the goals of the experiment. ▪ Design an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support their claim. ▪ Evaluate the accuracy of various methods for collecting data. ▪ Collect data and generate evidence to answer scientific questions or test design solutions under a range of conditions. ▪ Collect data about the performance of a proposed object, tool, process or system under a range of conditions.	Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that build, test, and revise conceptual, mathematical, physical, and empirical models. ▪ Design an investigation individually and collaboratively and test designs 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. ▪ Design and conduct an investigation individually and collaboratively, 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. ▪ Select appropriate tools to collect, record, analyze, and evaluate data. ▪ Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts. ▪ 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. ▪ Use investigations to gather evidence to support explanations or concepts.

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Analyzing and Interpreting Data Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.	Analyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations. ▪ Use and share pictures, drawings, and/or writings of observations. ▪ Use observations to describe patterns and/or relationships in the natural and designed worlds in order to answer scientific questions and solve problems. ▪ Make measurements of length to quantify data. ▪ Analyze data from tests of an object or tool to determine if a proposed object or tool functions as intended.	Analyzing data in 3–5 builds on K–2 and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. ▪ Display data in tables and graphs, using digital tools when feasible, to reveal patterns that indicate relationships. ▪ Use data to evaluate claims about cause and effect. ▪ Compare data collected by different groups in order to discuss similarities and differences in their findings. ▪ Use data to evaluate and refine design solutions. ▪ Interpret data to make sense of and explain phenomena, using logical reasoning, mathematics, and/or computation. ▪ Analyze data to refine a problem statement or the design of a proposed object, tool or process.	Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. ▪ Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible. ▪ Construct, analyze, and interpret graphical displays of data to identify linear and nonlinear relationships. ▪ Consider limitations of data analysis (e.g., measurement error), and seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials). ▪ Analyze and interpret data in order to determine similarities and differences in findings. ▪ Distinguish between causal and correlational relationships. ▪ Use graphical displays (e.g., maps) of large data sets to identify temporal and spatial relationships. ▪ Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria	Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. ▪ Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. ▪ Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. ▪ 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. ▪ Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. ▪ 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. ▪ Evaluate the impact of new data on a working explanation of a proposed process or system.

			for success.	

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Using Mathematics and Computational Thinking In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions.	Mathematical and computational thinking at the K–2 level builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world ▪ Decide when to use qualitative vs. quantitative data. ▪ Use counting and numbers to identify and describe patterns in the natural and designed worlds. ▪ Describe, measure, and compare quantitative attributes of different objects and display the data using simple graphs. ▪ Use quantitative data to compare two alternative solutions to a problem.	Mathematical and computational thinking at the 3–5 level builds on K–2 and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to compare alternative design solutions. ▪ Use mathematical thinking and/or computational outcomes to compare alternative solutions to an engineering problem. ▪ Organize simple data sets to reveal patterns that suggest relationships. ▪ Describe, measure, estimate, and graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems. ▪ Decide if qualitative or quantitative data is best to determine whether a proposed object or tool meets criteria for success.	Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. ▪ Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. ▪ Create algorithms (a series of ordered steps) to solve a problem. ▪ Apply concepts of ratio, rate, percent, basic operations, and simple algebra to scientific and engineering questions and problems. ▪ Use mathematical arguments to describe and support scientific conclusions and design solutions. ▪ Use digital tools, mathematical concepts, and arguments to test and compare proposed solutions to an engineering design problem.	Mathematical and computational thinking at the 9–12 level builds on K–8 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. ▪ Use mathematical or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. ▪ 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. ▪ Create a simple computational model or simulation of a designed device, process, or system.

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Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Constructing Explanations and Designing Solutions *The end-products of science are explanations and the end-products of engineering are solutions.* 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. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.	Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence or ideas in constructing explanations and designing solutions. ▪ Use information from direct or indirect observations to construct explanations. ▪ Use tools and materials provided to design a device or solution to a specific problem. ▪ Distinguish between opinions and evidence in one's own explanations. ▪ Generate and compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on prior experiences in K–2 and progresses to the use of evidence in constructing multiple explanations and designing multiple solutions. ▪ Construct explanations of observed quantitative relationships (e.g., the distribution of plants in the back yard). ▪ Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation or design a solution to a problem. ▪ Identify the evidence that supports particular points in an explanation. ▪ Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation. ▪ Apply scientific knowledge to solve design problems. ▪ Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the problem.	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 knowledge, principles, and theories. ▪ Construct explanations for either qualitative or quantitative relationships between variables. ▪ Apply scientific reasoning to show why the data are adequate for the explanation or conclusion. ▪ Base explanations on evidence obtained from sources (including their own experiments) and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. ▪ Undertake design projects, engaging in the design cycle, to construct and implement a solution that meets specific design criteria and constraints. ▪ Apply scientific knowledge and evidence to explain real-world phenomena, examples, or events. ▪ Construct explanations from models or representations. ▪ Apply scientific knowledge to design, construct, and test a design of an object, tool, process or system. ▪ Optimize performance of a design by prioritizing criteria, making	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 knowledge, principles, and theories. ▪ Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. ▪ Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. ▪ Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. ▪ Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. ▪ Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. ▪ Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of

			tradeoffs, testing, revising, and re-testing.	evidence, prioritized criteria, and tradeoff considerations.
Science and Engineering Practices	**K–2 Condensed Practices**	**3–5 Condensed Practices**	**6–8 Condensed Practices**	**9–12 Condensed Practices**

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Engaging in Argument from Evidence *Argumentation is the process by which explanations and solutions are reached.* In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to identify strengths and weaknesses of claims.	Engaging in argument from evidence in K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed world. ▪ Identify arguments that are supported by evidence. ▪ Listen actively to others' explanations and arguments and ask questions for clarification. ▪ Make a claim about the effectiveness of an object, tool, or solution that is based on relevant evidence.	Engaging in argument from evidence in 3–5 builds from K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world. ▪ Construct and/or support scientific arguments with evidence, data, and/or a model. ▪ Compare and refine arguments based on the strengths and weaknesses of the evidence presented. ▪ Respectfully provide and receive critiques on scientific arguments with peers by citing relevant evidence and posing specific questions. ▪ Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.	Engaging in argument from evidence in 6–8 builds from K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. ▪ Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation for a phenomenon or a solution to a problem. ▪ Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. ▪ Respectfully provide and receive critiques on scientific arguments by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. ▪ Compare two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. ▪ Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system, based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.	Engaging in argument from evidence in 9–12 builds from K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world. Arguments may also come from current scientific or historical episodes in science. ▪ Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. ▪ Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. ▪ Construct a counter-argument that is based on data and evidence that challenges another proposed argument. ▪ Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. ▪ Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

NGSS Science and Engineering Practices* (January 2013 Draft)

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Obtaining, Evaluating, and Communicating Information Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions. Scientists and engineers employ multiple sources to acquire information that is used to evaluate the merit and validity of claims, methods, and designs.	Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information. ▪ Read and comprehend grade-appropriate texts and media to acquire scientific and/or technical information. ▪ Critique and/or communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers. ▪ Record observations, thoughts, and ideas. ▪ Explain how specific images (e.g., a diagram showing how a machine works) contribute to and clarify a text. ▪ Obtain information by using various text features (e.g., headings, tables of contents, glossaries, electronic menus, icons).	Obtaining, evaluating, and communicating information in 3–5 builds on K–2 and progresses to evaluating the merit and accuracy of ideas and methods. ▪ Compare and/or combine across complex texts and/or other reliable media to acquire appropriate scientific and/or technical information. ▪ Determine the main idea of a scientific text and explain how it is supported by key details; summarize the text. ▪ Combine information in written text with that contained in corresponding tables, diagrams, and/or charts. ▪ Use multiple sources to generate and communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. ▪ Use models to share findings or solutions in oral and/or written presentations, and/or extended discussions. ▪ Obtain and combine information from books and/or other reliable media about potential solutions to a specific design problem.	Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods. ▪ Communicate scientific information and/or technical information (e.g. about a proposed object, tool, process, system) in different formats (e.g., verbally, graphically, textually, and mathematically). ▪ Gather, read, and communicate information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used. ▪ Read critically using scientific knowledge and reasoning to evaluate data, hypotheses, conclusions that appear in scientific and technical texts in light of competing information or accounts; provide an accurate summary of the text distinct from prior knowledge or opinions. ▪ Critically evaluate whether or not technical information on a device, tool or process is relevant to its suitability to solve a specific design problem.	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. ▪ Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. ▪ Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. ▪ Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. ▪ Compare, integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) in order to address a scientific question or solve a problem.