Appendix I
Science and Engineering Practices Progression Matrix

The Science and Engineering Practices

Science and engineering practices include the skills necessary to engage in scientific inquiry and engineering design. It is necessary to teach these so students develop an understanding and facility with the practices in appropriate contexts. The *Framework for K-12 Science Education* (NRC, 2012) identifies eight essential science and engineering practices:

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.

The field of science education refers to these as "practices" rather than "science processes" or "inquiry skills" for several reasons. First, skills are not separate from concepts:

> 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, 2012, p. 30

Including discussion of the practices in this section does not suggest that education should separate the science and engineering practices from disciplinary core ideas. Students cannot fully appreciate the nature of scientific knowledge without engaging with the science and engineering practices.

Second, science and engineering are dynamic:

> Second, a focus on practices (in the plural) avoids the mistaken impression that there is one distinctive approach common to all science—a single "scientific method"—or that uncertainty is a universal attribute of science. In reality, practicing scientists employ a broad spectrum of methods, and although science involves many areas of uncertainty as knowledge is developed, there are now many aspects of scientific knowledge that are so well established as to be unquestioned foundations of the culture and its technologies. It is only through engagement in the practices that students can recognize how such knowledge comes about and why some parts of scientific theory are more firmly established than others.
>
> NRC, 2012, p. 44

Finally, the term "practices" is also used in standards instead of "inquiry" or "skills" to emphasize that the practices are outcomes to be learned, not a method of instruction. The term "inquiry" has been used in both contexts for so long that many educators do not separate the two uses. So the term "practices" denotes the expected outcomes (development of skills) that result from instruction, whether instruction is inquiry-based or not.

Rationale

Chapter 3 of the NRC *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.[*]
>
> 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.
>
> 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, 2012, pp. 42–43

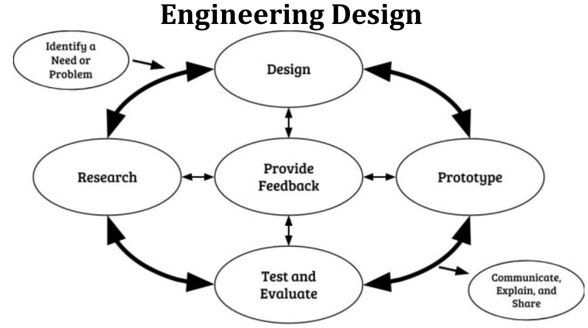
This appendix describes what students should be able to do relative to each of these eight practices. The charts presented in landscape format below are the "practices matrix": the specific capabilities that should be included in each practice for each grade span.

Scientific Inquiry and Engineering Design as Holistic and Dynamic Processes

Scientific inquiry and engineering design are dynamic and complex processes. Each requires engaging in a range of science and engineering practices to analyze and understand the natural and designed world. They are not defined by a linear, step-by-step approach. While students may learn and engage in distinct practices through their education, they should have periodic opportunities at each grade level to experience the holistic and dynamic processes represented below and described in the subsequent two pages.

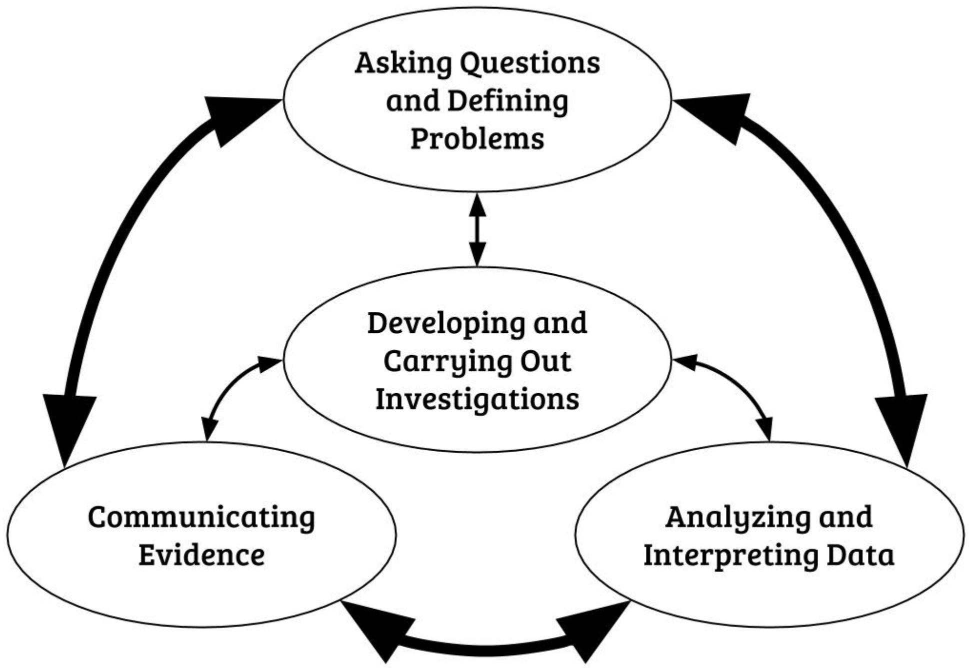
Scientific Inquiry

Engineering Design



[*] See Appendix VIII for more on crosscutting concepts.

Scientific Inquiry



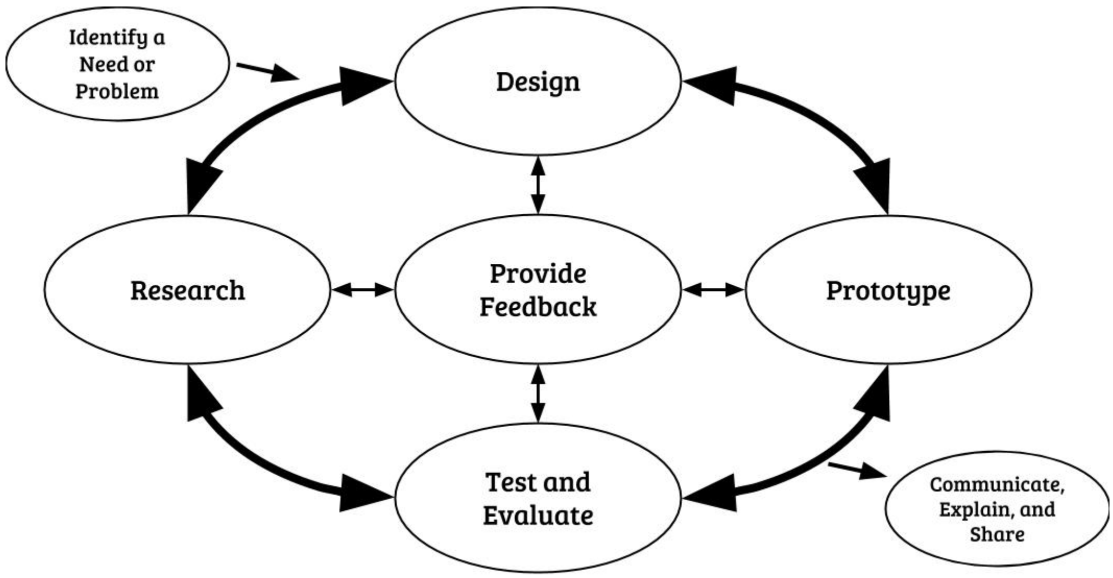
Asking questions and defining problems. Scientific questions arise in a variety of ways. They can be driven by curiosity about the world; inspired by the predictions of a model, theory, or findings from previous investigations; or stimulated by the need to solve a problem. Asking questions also leads to involvement in other practices.

Developing and carrying out investigations. Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model. It is important to state the goal of an investigation, predict outcomes, and plan a course of action that generates data to support claims in laboratory or field experiences. Variables must be identified as dependent or independent and intentionally varied from trial to trial or controlled across trials. Field investigations involve 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 likely includes elements of other practices.

Analyzing and interpreting data. Analyzing data involves identifying significant features and patterns, using mathematics to represent relationships between variables, and considering sources of error. Computational thinking is central, involving strategies for organizing and searching data, creating sequences of steps, and using and developing simulations or models.

Communicating evidence. Communicating explanations for the causes of phenomena is central to science. An explanation includes a claim that relates how a variable or variables relate to another variable or set of variables. A claim is often made in response to a question and in the process of answering the question. Argumentation is a process for reaching agreements about explanations and design solutions. Reasoning based on evidence is essential in identifying the best explanation for a natural phenomenon. Being able to communicate clearly and persuasively is critical to engaging with multiple sources of technical information and evaluating the merit and validity of claims, methods, and designs.

Engineering Design



Identify a need or a problem. To begin engineering design, a need or problem must be identified that an attempt can be made to solve, improve and/or fix. This typically includes articulation of criteria and constraints that will define a successful solution.

Research. Research is done to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and can be an ongoing part of design.

Design. All gathered information is used to inform the creations of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. A prototype is constructed based on the design model(s) and used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

Test and evaluate. The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype's performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, and refining the need or problem.

Provide feedback. Feedback through oral or written comments provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

Communicate, explain, and share. Communicating, explaining, and sharing the solution and design is essential to conveying how it works and does (or does not), solving the identified need or problem, and meeting the criteria and constraints. Communication of explanations must be clear and analytical.

Assumptions for Science and Engineering Practices

The following assumptions guided the articulation and integration of the science and engineering practices into the standards:

- **Practices give students the skills necessary to engage in analytical thinking.** Students must be able to use their knowledge and skills to analyze and understand scientific phenomena, designed systems, and real-world problems to successfully contribute to civic society and the economy. The science and engineering practices articulate the skills that are needed to achieve this.
- **Students in grades pre-K–12 should engage in all eight practices over each grade span.** All eight practices are accessible at some level to all children of every age. The matrix identifies only the capabilities students should acquire by the end of each grade span. Importantly, science and engineering practices should be generalizable across core ideas and particular concepts. Curriculum developers and educators determine the strategies that advance students' abilities to use the practices.
- **Practices grow in complexity and sophistication across the grades.** Students' abilities to use the practices grow over time. The NRC *Framework* suggests how students' capabilities to use each of the practices should progress as they mature and engage in STE learning. While these progressions are derived from Chapter 3 of the NRC *Framework*, they are refined based on experiences in crafting the standards.
- **Each practice may reflect science or engineering.** Each of the eight practices can be used in the service of scientific inquiry and engineering design. One way to determine if a practice is being used for science or engineering is to ask about the goal of the activity. Is the goal to answer a question about natural phenomena? If so, students are likely engaged in science. Is the purpose to define and solve a problem to meet the needs of people? If so, students are likely engaged in engineering.
- **Practices represent what students are expected to do; they do not represent teaching methods or a curriculum.** The goal of standards is to describe what students should be able to do, rather than how they should be taught. The science and engineering practices are skills to be learned as a result of instruction; they do not define activities.
- **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 computational thinking" may include some aspects of "analyzing and interpreting data." Just as it is important for students to carry out each of the individual practices, it is important for them to see the connections among the eight practices.
- **Standards focus on some but not all skills associated with a practice.** The matrix identifies a number of particular skills for each practice, listing the components of each practice as a bulleted list within each grade span. Individual standards can include only one, or perhaps two, skills.
- **Engagement in practices is language intensive and requires students to participate in relevant experiences and scientific and technical discourse.** The practices offer rich opportunities and demands for language learning while advancing STE learning for all students (Lee et al., 2013).

Brief Description of Each Science and Engineering Practice

Each practice is described briefly below; for more information, see the NRC *Framework* (NRC, 2012). The practices matrix follows the descriptions.

Practice 1. Asking Questions and Defining Problems

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world; inspired by the predictions of a model, a theory, or findings from previous investigations; or stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through 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 possible trade-offs? What evidence is necessary to determine which solution is best?

Asking questions and defining problems also involves asking questions about data, claims that are made, and proposed designs. It is important to realize that asking a question also leads to involvement in another practice. A student can ask a question about data that will lead to further analysis and interpretation. Or a student might ask a question that leads to planning and design, an investigation, or the refinement of a design.

Practice 2. Developing and Using Models

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

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

In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. They can also be used to visualize and refine a design or to communicate a design’s features. Prototypes are physical or simulated instantiations of a model that can be manipulated and tested for specified variables, design features, or functions.

Practice 3. Planning and Carrying Out Investigations

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, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena. Data are not evidence until used in the process of supporting a claim. Students should use reasoning and scientific ideas, principles, and theories to show why data can be considered evidence.

Over time, students should become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as dependent or independent; which should be treated as inputs and intentionally varied from trial to trial; and which should 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.

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.
>
> 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, 2012, pp. 61–62

As students mature, they expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students also improve their ability to interpret data by identifying significant features and patterns, using mathematics to represent relationships between variables, and taking into account sources of error. When possible and feasible, students should use digital tools to analyze and interpret data. Students’ analysis and interpretation of data result in evidence to support their conclusions.

Practice 5. Using Mathematics and Computational Thinking

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

Practice 6. Constructing Explanations and Designing Solutions

The goal of science is to construct explanations for the causes of phenomena. Students construct their own explanations, as well as apply standard explanations they learn about through instruction. The NRC *Framework* states the following about explanation:

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

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

The goal of engineering is to systematically solve problems. Engineering design involves defining the problem, then generating, testing, and improving solutions. The NRC *Framework* describes this practice as follows.

> 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, 2012, pp. 68–69

Practice 7. Engaging in Argument from Evidence

Argumentation is a process for reaching agreements about explanations and design 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 argumentation is critical if students are to understand the culture in which scientists and engineers live, and how to apply science and engineering for the benefit of society. As such, argument is a process based on evidence and reasoning that leads to explanations acceptable by the scientific community and design solutions acceptable by the engineering community.

Argument in science goes beyond reaching agreements in explanations and design solutions. 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 evaluate claims. Whether investigating a phenomenon, testing a design, or constructing a model to provide a mechanism for an explanation, students are expected to use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits.

Practice 8. Obtaining, Evaluating, and Communicating Information

Being able to read, interpret, and produce scientific and technical text is a fundamental practice 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, on the Internet, or at 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 use multiple sources of information to evaluate the merit and validity of claims, methods, and designs. Communicating information, evidence, and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays, and equations, as well as orally and in writing.

[This appendix draws from and is an adaptation of the NGSS, Appendix F.]

References

Bell, P., Bricker, L., Tzou, C., Lee, T., & 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.

Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher*, *42*(4), 223-223.

National Research Council (NRC). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Science and Engineering Practices	**Pre-K–2 Condensed Practices**	**3–5 Condensed Practices**	**6–8 Condensed Practices**	**9–12 Condensed Practices**
1. 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 pre-K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested.	Asking questions and defining problems in 3–5 builds on pre-K–2 experiences and progresses to specifying qualitative relationships.	Asking questions and defining problems in 6–8 builds on pre-K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.	Asking questions and defining problems in 9–12 builds on pre-K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.
	• Ask questions based on observations to find more information about the natural and/or designed worlds.	• Ask questions about what would happen if a variable is changed.	• Ask questions: o That arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. o To identify and/or clarify evidence and/or the premise(s) of an argument. o To determine relationships between independent and dependent variables and relationships in models. o To clarify and/or refine a model, an explanation, or an engineering problem.	• Ask questions: o That arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. o That arise from examining models or a theory, to clarify and/or seek additional information and relationships. o To determine relationships, including quantitative relationships, between independent and dependent variables. o To clarify and refine a model, an explanation, or an engineering problem.

Science and Engineering Practices	**Pre-K–2 Condensed Practices**	**3–5 Condensed Practices**	**6–8 Condensed Practices**	**9–12 Condensed Practices**
	• Ask and/or identify questions that can be answered by an investigation.	• Identify scientific (testable) and non-scientific (non-testable) questions. • Ask questions that can be investigated and predict reasonable outcomes based on patterns, such as cause and effect relationships.	• Ask questions that require sufficient and appropriate empirical evidence to answer. • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	• 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 questions that challenge the premise(s) of an argument or the interpretation of a data set.	• 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 simple problem that can be solved through the development of a new or improved object or tool.	• 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, process, or system and includes several criteria for success and constraints on materials, time, or cost.	• 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.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
2. 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.	Modeling in pre-K–2 builds on prior experiences and progresses to include using and developing models (e.g., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.	Modeling in 3–5 builds on pre-K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.	Modeling in 6–8 builds on pre-K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.	Modeling in 9–12 builds on pre-K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
	• Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences.	• Identify limitations of models.	• Evaluate limitations of a model for a proposed object or tool.	• 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 and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed worlds.	• Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design	• Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among	• 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

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Measurements and observations are used to revise models and designs.		solution. • Develop and/or use models to describe and/or predict phenomena.	variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms.	limitations.
	• Develop a simple model based on evidence to represent a proposed object or tool.	• Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	• Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
3. 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 pre-K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on pre-K–2 experiences and progresses to include investigations that *control variables* and provide evidence to support explanations or design solutions.	Planning and carrying out investigations in 6–8 builds on pre-K–5 experiences and progresses to include investigations that use *multiple variables* and provide evidence to support explanations or solutions.	Planning and carrying out investigations in 9–12 builds on pre-K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
	• With guidance, plan and conduct an investigation in collaboration with peers (for K). • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question.	• Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.	• Plan 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 many data are needed to support a claim. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	• 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 that 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 the types, quantity, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time); and refine the design accordingly.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
				• Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.
	• Evaluate different ways of observing and/or measuring a phenomenon to determine which way to answer a question.	• Evaluate appropriate methods and/or tools for collecting data.	• Evaluate the accuracy of various methods for collecting data.	• Select appropriate tools to collect, record, analyze, and evaluate data.
	• Make observations (first-hand or from media) and/or measurements to collect data that can be used to make comparisons. • Make observations (first-hand or from media) and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal. • Make predictions based on prior experiences.	• Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. • Make predictions about what would happen if a variable changes. • Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.	• Collect data to serve as the basis for 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.	• 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.

Science and Engineering Practices	Pre-K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
4. 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—	Analyzing data in pre-K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations.	Analyzing data in 3–5 builds on pre-K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used.	Analyzing data in 6–8 builds on pre-K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.	Analyzing data in 9–12 builds on pre-K–8 experiences 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.
	• Record information (observations, thoughts, and ideas). • Use and share pictures, drawings, and/or writings of observations. • Use observations (first-hand or from media) to describe patterns and/or relationships in the natural and designed worlds in order to answer scientific questions and solve problems. • Compare predictions (based on prior experiences) to what occurred (observable events).	• Represent data in tables and/or various graphical displays (bar graphs, pictographs, and/or pie charts) to reveal patterns that indicate relationships.	• Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships. • Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships. • Distinguish between causal and correlational relationships in data. • Analyze and interpret data to provide evidence for phenomena.	• 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.
		• Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation.	• Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools	• Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits)

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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.			when feasible.	to scientific and engineering questions and problems, using digital tools when feasible.
			• Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials).	• Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
		• Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.	• Analyze and interpret data to determine similarities and differences in findings.	• Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
	• Analyze data from tests of an object or tool to determine if it works as intended.	• Analyze data to refine a problem statement or the design of a proposed object, tool, or process. • Use data to evaluate and refine design solutions.	• Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.	• 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.

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5. 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 in pre-K–2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed worlds.	Mathematical and computational thinking in 3–5 builds on pre-K–2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions.	Mathematical and computational thinking in 6–8 builds on pre-K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments.	Mathematical and computational thinking in 9–12 builds on pre-K–8 and experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
	• Decide when to use qualitative versus quantitative data.	• Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success.		
	• Use counting and numbers to identify and describe patterns in the natural and designed worlds.	• Organize simple data sets to reveal patterns that suggest relationships.	• Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends.	• Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
	• Describe, measure, and/or compare quantitative attributes of different objects and display the data using simple graphs.	• Describe, measure, estimate, and/or graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems.	• Use mathematical representations to describe and/or support scientific conclusions and design solutions.	• Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

	• Use quantitative data to compare two alternative solutions to a problem.	• Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.	• Create algorithms (a series of ordered steps) to solve a problem. • Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems. • Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.	• 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/m^3, acre-feet, etc.).

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6. 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	Constructing explanations and designing solutions in pre-K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.	Constructing explanations and designing solutions in 3–5 builds on pre-K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.	Constructing explanations and designing solutions in 6–8 builds on pre-K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.	Constructing explanations and designing solutions in 9–12 builds on pre-K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
	• Use information from observations (first-hand and from media) to construct an evidence-based account for natural phenomena.	• Construct an explanation of observed relationships (e.g., the distribution of plants in the backyard).	• Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations.	• Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
		• Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.	• Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas,	• 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.

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on how well the proposed solutions meet criteria and constraints.			principles, and/or evidence to construct, revise, and/or use an explanation for real-world phenomena, examples, or events.	• Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
		• Identify the evidence that supports particular points in an explanation.	• Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.	• 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.
	• Use tools and/or materials to design and/or build a device that solves a specific problem. • Generate and/or compare multiple solutions to a problem.	• Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.	• Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process, or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	• 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.

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7. Engaging in Argument from Evidence *Argumentation is the process by which evidence-based conclusions 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 evaluate claims.	Engaging in argument from evidence in pre-K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed worlds.	Engaging in argument from evidence in 3–5 builds on pre-K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed worlds.	Engaging in argument from evidence in 6–8 builds on pre-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 worlds.	Engaging in argument from evidence in 9–12 builds on pre-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 worlds. Arguments may also come from current scientific or historical episodes in science.
	• Identify arguments that are supported by evidence. • Distinguish between explanations that account for all gathered evidence and those that do not. • Analyze why some evidence is relevant to a scientific question and some is not. • Distinguish between opinions and evidence in one's own explanations.	• Compare and refine arguments based on an evaluation of the evidence presented. • Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation.	• Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts.	• 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.
	• Listen actively to arguments to indicate agreement or disagreement based on evidence, and/or to retell the main points of the argument.	• Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing	• Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to	• Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to

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		specific questions.	questions that elicit pertinent elaboration and detail.	diverse perspectives, and determining what additional information is required to resolve contradictions.
	• Construct an argument with evidence to support a claim.	• Construct and/or support an argument with evidence, data, and/or a model. • Use data to evaluate claims about cause and effect.	• Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	• Construct, use, and/or present an oral and written argument or counterarguments based on data and evidence.
	• Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence.	• 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.	• 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. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	• 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).

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8. 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 and in writing. Scientists and engineers employ multiple sources to obtain information that is used to evaluate the merit and validity of claims, methods, and designs.	Obtaining, evaluating, and communicating information in pre-K–2 builds on prior experiences and uses observations and texts to communicate new information.	Obtaining, evaluating, and communicating information in 3–5 builds on pre-K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods.	Obtaining, evaluating, and communicating information in 6–8 builds on pre-K–5 experiences and progresses to evaluating the merit and validity of ideas and methods.	Obtaining, evaluating, and communicating information in 9–12 builds on pre-K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.
	• Read grade-appropriate texts and/or use media to obtain scientific and/or technical information to determine patterns in and/or evidence about the natural and designed worlds.	• Read and comprehend grade-appropriate complex texts and/or other reliable media to summarize and obtain scientific and technical ideas and describe how they are supported by evidence. • Compare and/or combine complex texts and/or other reliable media to support an investigation or design.	• Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed worlds.	• 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.
	• Describe how specific images (e.g., a diagram showing how a machine works) support a scientific or engineering idea.	• Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support an investigation or design.	• Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings.	• 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.

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	• Obtain information using various texts, text features (e.g., headings, tables of contents, glossaries, electronic menus, icons), and other media that will be useful in answering a scientific question and/or supporting a scientific claim.	• Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem.	• Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and set of methods used, and describe how they are supported or not supported by evidence. • Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts.	• 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 information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers that provide detail about scientific ideas, practices, and/or design ideas.	• Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.	• Communicate scientific and/or technical information (e.g., about a proposed object, tool, process, system) in writing and/or through oral presentations.	• 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 (including orally, graphically, textually, and mathematically).