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.

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 *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.

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 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.