Planning for New Science Standards Workshop II - Handouts

#	Title	Distribution
1	Science Standards Timeline	One per participant
2	Appendix F - pages 2-3	One per participant
3	Appendix G - pages 1-3	One per participant
4	How People Learn - Overview	One per participant
5	Conceptual Flow Example	One per group
6	DCI - LS.2 - Framework pages 150-152	One per participant
7	Example of DCI Match	One per group
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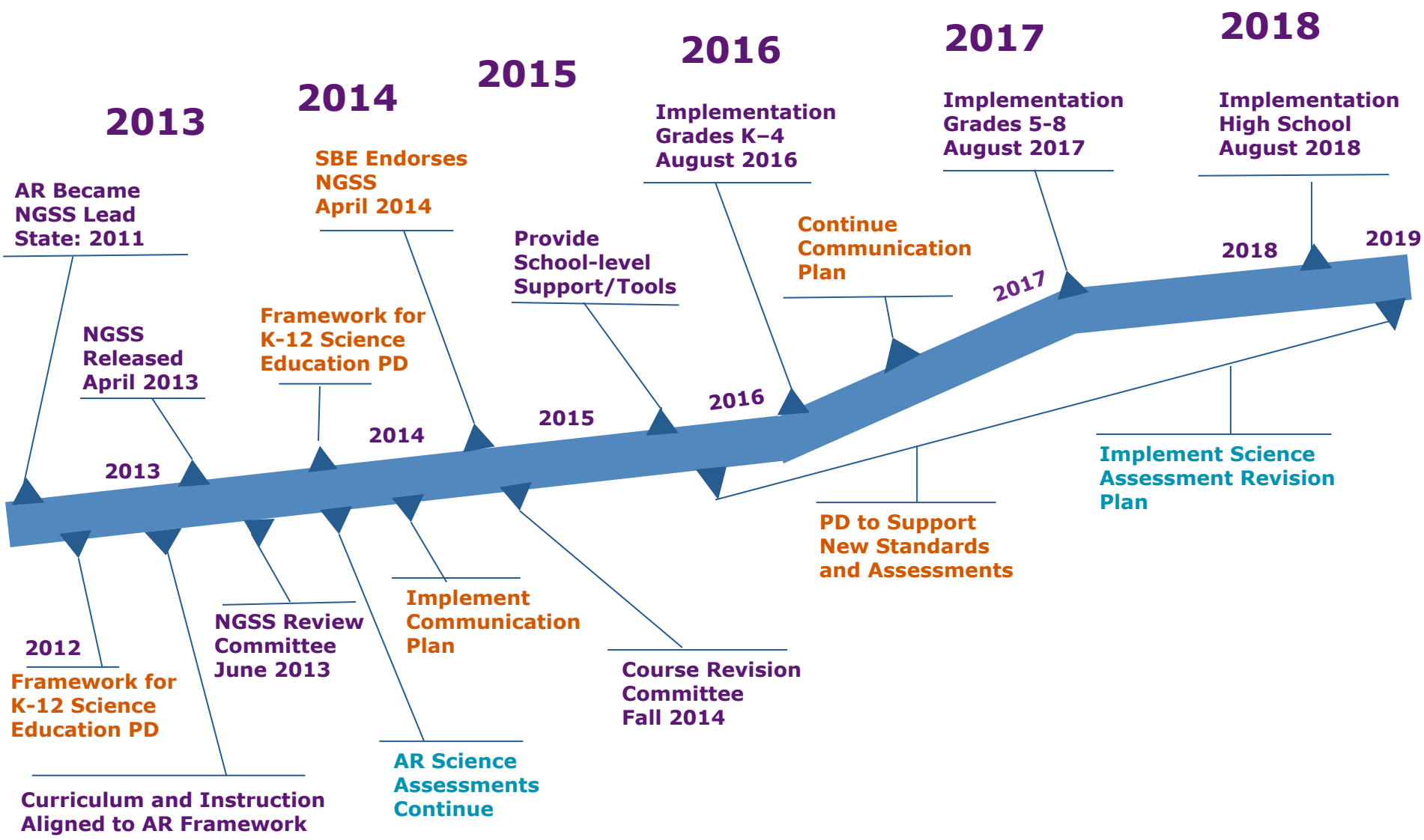
9	Arkansas Grade 7 Released Item	One per group
10	PQP Chart - Blank	One per participant
11	Essential Question Check Sheet	One per participant
12	SEPs - Excerpt from Appendix F	One per participant
13	Practices Added to Conceptual Flow	One per group
14	PQP Chart - Completed	One per participant
15	Crosscutting Concepts - Framework Pages 85-101	Enough copies to have 7 groups - 1 for each CCC
16	Sci. and Eng. Differ - Framework Pages 46-48	One per participant
17	Appendix F - pages 4-15	Enough copies to have 7 groups - 1 for each practice 2-8
18	Reflecting on the Practices - Framework p. 78-79	One per participant

Science Standards Timeline



Curriculum and Instruction **Assessment** **Professional Development**

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. 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, with a core disciplinary idea and crosscutting concept, 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 students not only "know" science concepts; but also, students 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 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. It is recommended 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 this section of the NGSS appendices 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. The "Practices Matrix" is included, which lists the specific capabilities included in each practice for each grade band (K-2, 3-5, 6-8, 9-12).

Guiding Principles

The development process of the standards provided insights into science and engineering practices. These insights are shared in the following guiding principles:

Students in grades K-12 should engage in all eight practices over each grade band. All eight practices are accessible at some level to young children; students' abilities to use the practices grow over time. However, the NGSS only identifies the capabilities students are expected to acquire by the end of each grade band (K-2, 3-5, 6-8, and 9-12). Curriculum developers and teachers determine strategies that advance students' abilities to use the practices.

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" begins at the kindergarten level with guided 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 experiences in crafting the NGSS and feedback received from reviewers.

Each practice may reflect science or engineering. Each of the eight practices can be used in the service of scientific inquiry or engineering design. The best way to ensure 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? If so, students are doing science. Is the purpose to define and solve a problem? If so, students 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 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. The NGSS avoids such suggestions since the goal is to describe what students should be able to do, rather than how they should be taught. For example, it was suggested for the NGSS to recommend certain teaching strategies such as using biomimicry—the application of biological features to solve 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, biomimicry and similar teaching approaches are more closely related to curriculum and instruction than to assessment. Hence, the decision was made not to include biomimicry 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 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.

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, described in this section, lists the components of each practice as a bulleted list within each grade band. As the performance expectations were developed, it became clear that it's too much to expect each performance to reflect all components of a given practice. The most appropriate aspect of the practice is identified for each performance expectation.

Engagement in practices is language intensive and requires students to participate in classroom science discourse. The practices offer rich opportunities and demands for language learning while advancing science learning for all students (Lee, Quinn, & Valdés, in press). English language learners, students with disabilities that involve language processing, students with limited literacy development, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English" stand to gain from science learning that involves language-intensive scientific and engineering practices. When supported appropriately, these students are capable of learning science through their emerging language and comprehending and carrying out sophisticated language functions (e.g., arguing from evidence, providing explanations, developing models) using less-than-perfect English. By engaging in such practices, moreover, they simultaneously build on their understanding of science and their language proficiency (i.e., capacity to do more with language).

On the following pages, each of the eight practices is briefly described. Each description 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 the *practices matrix*. During development of the NGSS, the practices matrix was revised several times to reflect improved understanding of how the practices connect with the disciplinary core ideas.

Appendix G – Crosscutting Concepts

> *Crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas.* — Framework p. 233

A Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts (*Framework*) recommends science education in grades K-12 be built around three major dimensions: scientific and engineering practices; crosscutting concepts that unify the study of science and engineering through their common application across fields; and core ideas in the major disciplines of natural science. The purpose of this appendix is to describe the second dimension—crosscutting concepts—and to explain its role in the *Next Generation Science Standards* (NGSS).

The *Framework* identifies seven crosscutting concepts that bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas (pp. 2 and 8), and develop a coherent and scientifically based view of the world (p. 83.) The seven crosscutting concepts presented in Chapter 4 of the *Framework* are as follows:

1. *Patterns.* Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

2. *Cause and effect: Mechanism and explanation*. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3. *Scale, proportion, and quantity.* In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4. *Systems and system models.* Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. *Energy and matter: Flows, cycles, and conservation.* Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

6. *Structure and function.* The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

7. *Stability and change.* For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

The *Framework* notes that crosscutting concepts are featured prominently in other documents about what all students should learn about science for the past two decades. These have been called "themes" in *Science for All Americans* (AAA 1989) and *Benchmarks for Science Literacy* (1993), "unifying principles" in *National Science Education Standards* (1996), and "crosscutting ideas" NSTA's *Science Anchors Project* (2010). Although these ideas have been consistently included in previous standards documents the Framework recognizes that "students have often been expected to

build such knowledge without any explicit instructional support. Hence the purpose of highlighting them as Dimension 2 of the framework is to elevate their role in the development of standards, curricula, instruction, and assessments." (p. 83) The writing team has continued this commitment by weaving crosscutting concepts into the performance expectations for all students—so they cannot be left out.

Guiding Principles

The *Framework* recommended crosscutting concepts be embedded in the science curriculum beginning in the earliest years of schooling and suggested a number of guiding principles for how they should be used. The development process of the standards provided insights into the crosscutting concepts. These insights are shared in the following guiding principles.

Crosscutting concepts can help students better understand core ideas in science and engineering. When students encounter new phenomena, whether in a science lab, field trip, or on their own, they need mental tools to help engage in and come to understand the phenomena from a scientific point of view. Familiarity with crosscutting concepts can provide that perspective. For example, when approaching a complex phenomenon (either a natural phenomenon or a machine) an approach that makes sense is to begin by observing and characterizing the phenomenon in terms of patterns. A next step might be to simplify the phenomenon by thinking of it as a system and modeling its components and how they interact. In some cases it would be useful to study how energy and matter flow through the system, or to study how structure affects function (or malfunction). These preliminary studies may suggest explanations for the phenomena, which could be checked by predicting patterns that might emerge if the explanation is correct, and matching those predictions with those observed in the real world.

Crosscutting concepts can help students better understand science and engineering practices. Because the crosscutting concepts address the fundamental aspects of nature, they also inform the way humans attempt to understand it. Different crosscutting concepts align with different practices, and when students carry out these practices, they are often addressing one of these crosscutting concepts. For example, when students analyze and interpret data, they are often looking for patterns in observations, mathematical or visual. The practice of planning and carrying out an investigation is often aimed at identifying cause and effect relationships: if you poke or prod something, what will happen? The crosscutting concept of "Systems and System Models" is clearly related to the practice of developing and using models.

Repetition in different contexts will be necessary to build familiarity. Repetition is counter to the guiding principles the writing team used in creating performance expectations to reflect the core ideas in the science disciplines. In order to reduce the total amount of material students are held accountable to learn, repetition was reduced whenever possible. However, crosscutting concepts are repeated within grades at the elementary level and grade-bands at the middle and high school levels so these concepts "become common and familiar touchstones across the disciplines and grade levels." (p. 83)

Crosscutting concepts should grow in complexity and sophistication across the grades. Repetition alone is not sufficient. As students grow in their understanding of the science disciplines, depth of understanding crosscutting concepts should grow as well. The writing team has adapted and added to the ideas expressed in the *Framework* in developing a matrix for use in crafting performance expectations that describe student understanding of the crosscutting concepts. The matrix is found at the end of this section.

Crosscutting concepts can provide a common vocabulary for science and engineering. The practices, disciplinary core ideas, and crosscutting concepts are the same in science and engineering. What is different is how and why they are used—to explain natural phenomena in science, and to solve a problem or accomplish a goal in engineering. Students need both types of experiences to develop a deep and flexible understanding of how these terms are applied in each of these closely allied fields. As crosscutting concepts are encountered repeatedly across academic disciplines, familiar vocabulary can enhance engagement and understanding for English language learners, students with language processing difficulties, and students with limited literacy development.

Crosscutting concepts should not be assessed separately from practices or core ideas. Students should not be assessed on their ability to define "pattern," "system," or any other crosscutting concepts as a separate vocabulary word. To capture the vision in the *Framework,* students should be assessed on the extent to which they have achieved a coherent scientific worldview by recognizing similarities among core ideas in science or engineering that may at first seem very different, but are united through crosscutting concepts.

Performance expectations focus on some but not all capabilities associated with a crosscutting concept. As core ideas grow in complexity and sophistication across the grades it becomes more and more difficult to express them fully in performance expectations. Consequently, most performance expectations reflect only some aspects of a crosscutting concept. These aspects are indicated in the right-hand foundation box in each of the standards. All aspects of each core idea considered by the writing team can be found in the matrix at the end of this section.

Crosscutting concepts are for *all* students. Crosscutting concepts raise the bar for students who have not achieved at high levels in academic subjects and often assigned to classes that emphasize "the basics," which in science may be taken to provide primarily factual information and lower-order thinking skills. Consequently, it is essential that *all students* engage in using crosscutting concepts, which could result in leveling the playing field and promoting deeper understanding for all students.

Inclusion of Nature of Science and Engineering Concepts. Sometimes included in the crosscutting concept foundation boxes are concepts related to materials from the "Nature of Science" or "Science, Technology, Society, and the Environment." These are not to be confused with the "Crosscutting Concepts" but rather represent an organizational structure of the NGSS recognizing concepts from both the Nature of Science and Science, Technology, Society, and the Environment that extend across all of the sciences. Readers should use Appendices H and J for further information on these ideas.

Progression of Crosscutting Concepts Across the Grades

Following is a brief summary of how each crosscutting concept increases in complexity and sophistication across the grades as envisioned in the *Framework*. Examples of performance expectations illustrate how these ideas play out in the NGSS.

1. "Patterns exist everywhere—in regularly occurring shapes or structures and in repeating events and relationships. For example, patterns are discernible in the symmetry of flowers and snowflakes, the cycling of the seasons, and the repeated base pairs of DNA." (p. 85)

While there are many patterns in nature, they are not the norm since there is a tendency for disorder

How People Learn

In ***How People Learn*** *(National Research Council, 2000),* the authors summarize three key ideas about learning based on an exhaustive study of the research (p.14-19). These three findings about student learning have parallel implications for classroom instruction (p. 19-21), which then suggest a translation of those implications into curriculum materials. As the authors state, these three findings imply the following for students and teachers:

FIRST KEY FINDING
Prior Knowledge

Students come to the classroom with preconceptions about how the world works. If their initial knowledge is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but never to their preconceptions outside the classroom.

SECOND KEY FINDING
Conceptual Frameworks

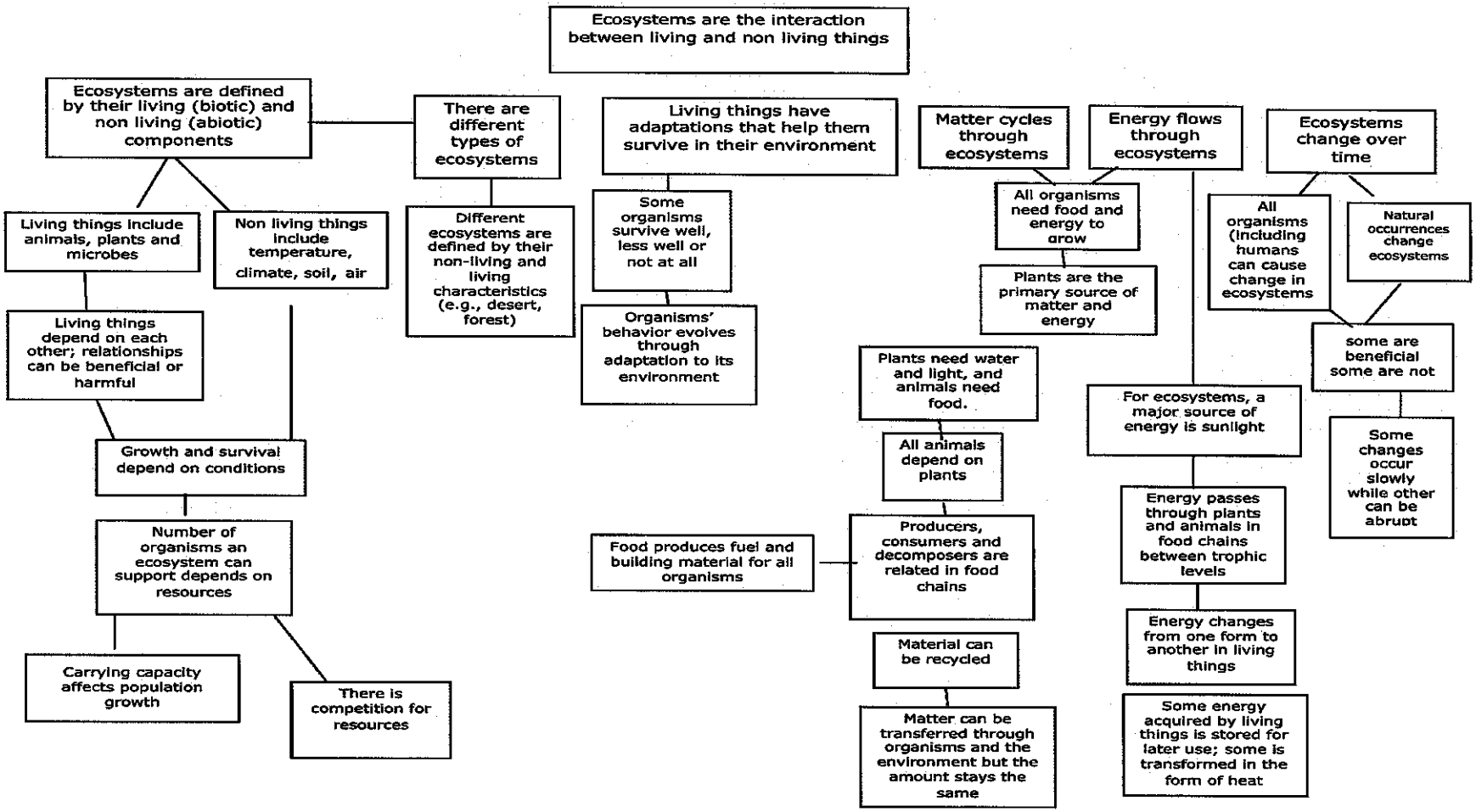
To develop competence in an area of a science discipline, students must, (a) have a deep foundation of usable knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) be able to organize that knowledge in ways that facilitate retrieval and application.

THIRD KEY FINDING
Metacognition

Students must be taught explicitly to take control of their own learning by defining goals and monitoring their progress in achieving them.

Adapted from ***How People Learn*** (NRC, 2000).
Washington, D. C.: National Academy Press.

Collaborative Conceptual Flow



Conceptual Flow Developed by the K-12 Alliance/WestEd

By the end of grade 12. In complex animals, the brain is divided into several distinct regions and circuits, each of which primarily serves dedicated functions, such as visual perception, auditory perception, interpretation of perceptual information, guidance of motor movement, and decision making about actions to take in the event of certain inputs. In addition, some circuits give rise to emotions and memories that motivate organisms to seek rewards, avoid punishments, develop fears, or form attachments to members of their own species and, in some cases, to individuals of other species (e.g., mixed herds of mammals, mixed flocks of birds). The integrated functioning of all parts of the brain is important for successful interpretation of inputs and generation of behaviors in response to them.

Core Idea LS2 Ecosystems: Interactions, Energy, and Dynamics

How and why do organisms interact with their environment and what are the effects of these interactions?

Ecosystems are complex, interactive systems that include both biological communities (biotic) and physical (abiotic) components of the environment. As with individual organisms, a hierarchal structure exists; groups of the same organisms (species) form populations, different populations interact to form communities, communities live within an ecosystem, and all of the ecosystems on Earth make up the biosphere. Organisms grow, reproduce, and perpetuate their species by obtaining necessary resources through interdependent relationships with other organisms and the physical environment. These same interactions can facilitate or restrain growth and enhance or limit the size of populations, maintaining the balance between available resources and those who consume them. These interactions can also change both biotic and abiotic characteristics of the environment. Like individual organisms, ecosystems are sustained by the continuous flow of energy, originating primarily from the sun, and the recycling of matter and nutrients within the system. Ecosystems are dynamic, experiencing shifts in population composition and abundance and changes in the physical environment over time, which ultimately affects the stability and resilience of the entire system.

LS2.A: INTERDEPENDENT RELATIONSHIPS IN ECOSYSTEMS

How do organisms interact with the living and nonliving environments to obtain matter and energy?

Ecosystems are ever changing because of the interdependence of organisms of the same or different species and the nonliving (physical) elements of the environment. Seeking matter and energy resources to sustain life, organisms in an ecosystem interact with one another in complex feeding hierarchies of producers, consumers, and decomposers, which together represent a food web. Interactions between organisms may be predatory, competitive, or mutually beneficial. Ecosystems have carrying capacities that limit the number of organisms (within populations) they can support. Individual survival and population sizes depend on such factors as predation, disease, availability of resources, and parameters of the physical environment. Organisms rely on physical factors, such as light, temperature, water, soil, and space for shelter and reproduction. Earth's varied combinations of these factors provide the physical environments in which its ecosystems (e.g., deserts, grasslands, rain forests, and coral reefs) develop and in which the diverse species of the planet live. Within any one ecosystem, the biotic interactions between organisms (e.g., competition, predation, and various types of facilitation, such as pollination) further influence their growth, survival, and reproduction, both individually and in terms of their populations.

Grade Band Endpoints for LS2.A

By the end of grade 2. Animals depend on their surroundings to get what they need, including food, water, shelter, and a favorable temperature. Animals depend on plants or other animals for food. They use their senses to find food and water, and they use their body parts to gather, catch, eat, and chew the food. Plants depend on air, water, minerals (in the soil), and light to grow. Animals can move around, but plants cannot, and they often depend on animals for pollination or to move their seeds around. Different plants survive better in different settings because they have varied needs for water, minerals, and sunlight.

By the end of grade 5. The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants

for food and other animals eat the animals that eat plants. Either way, they are "consumers." Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil for plants to use. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.

By the end of grade 8. Organisms and populations of organisms are dependent on their environmental interactions both with other living things and with nonliving factors. Growth of organisms and population increases are limited by access to resources. In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.

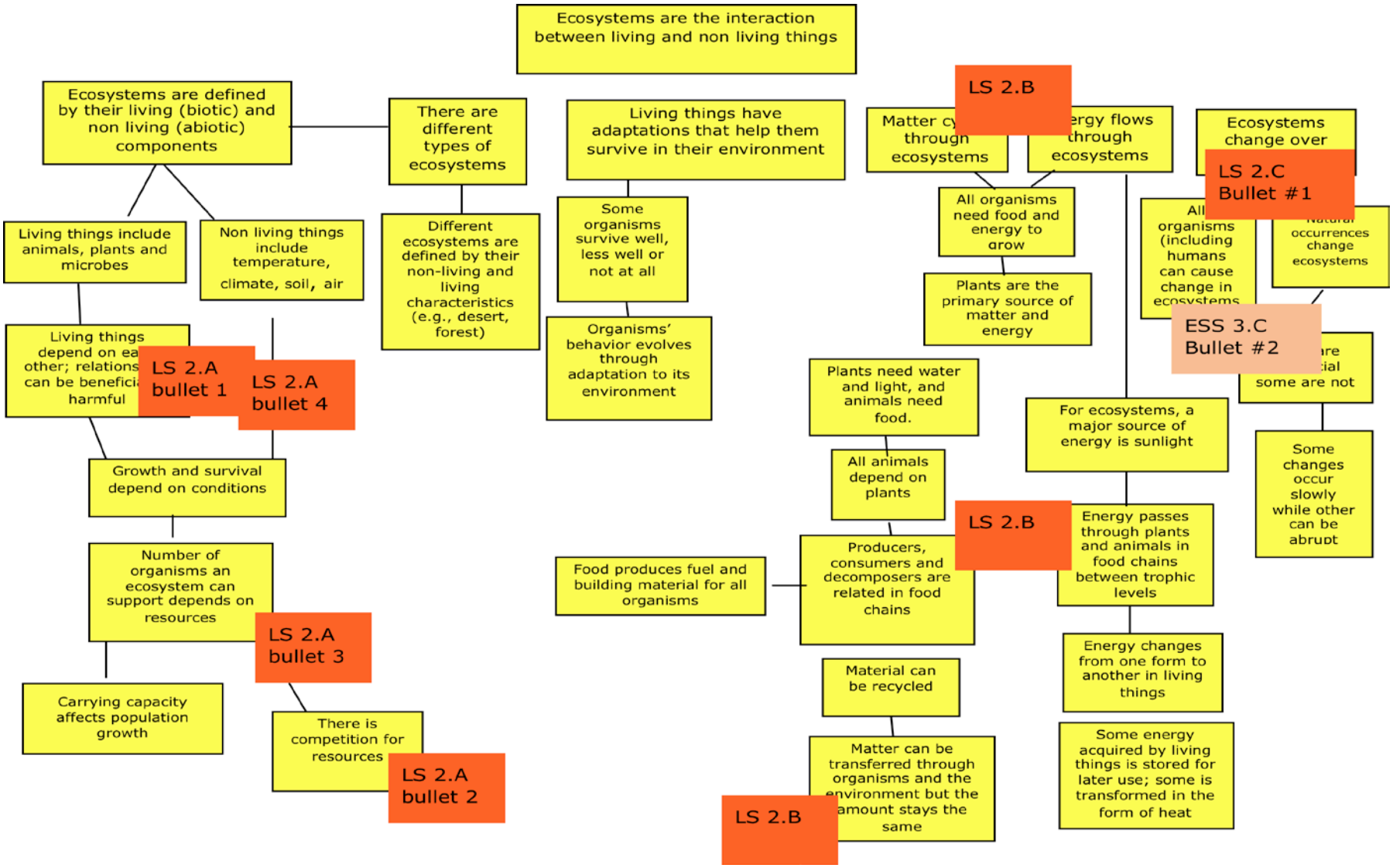
By the end of grade 12. Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.

LS2.B: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS

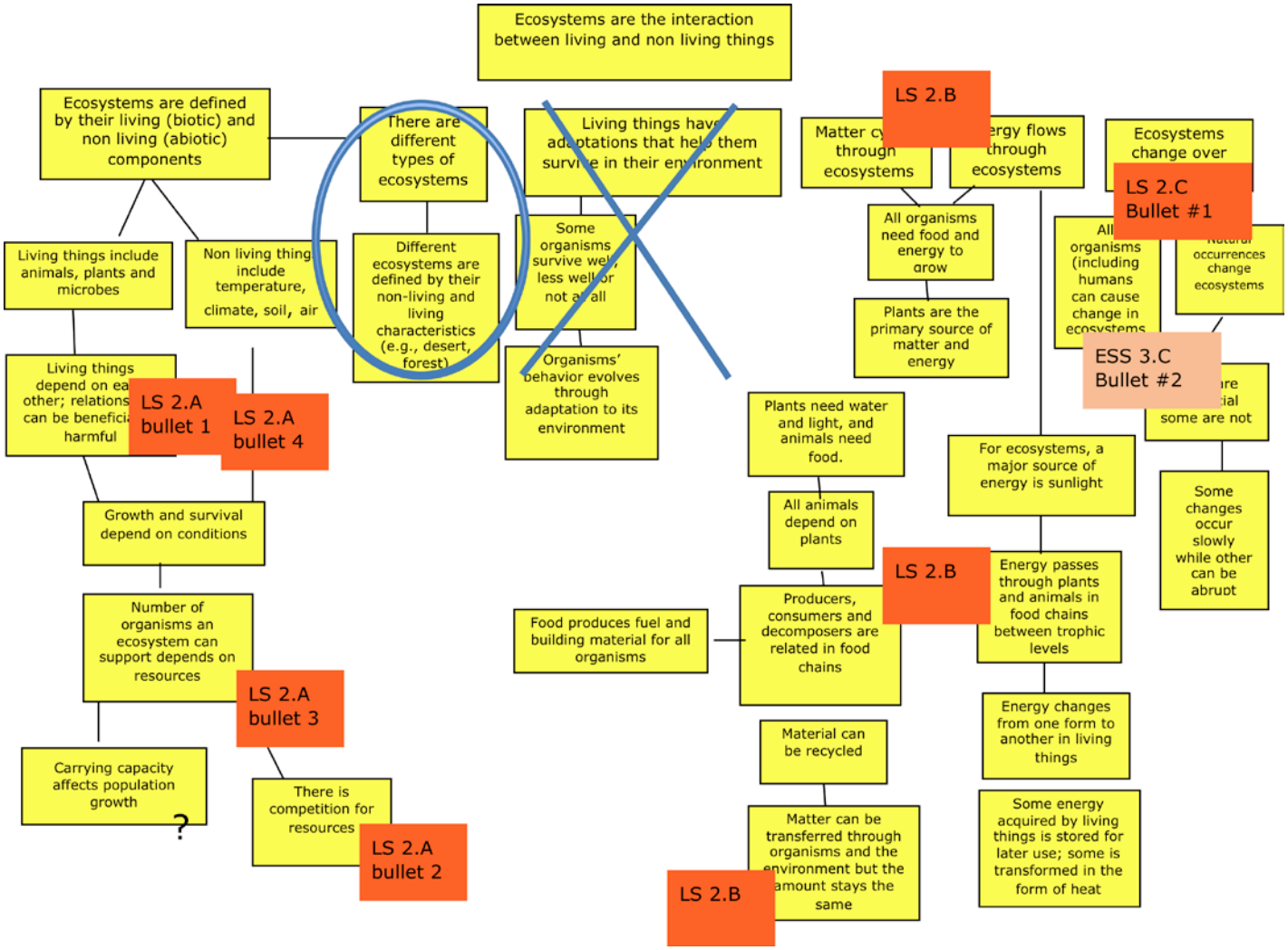
How do matter and energy move through an ecosystem?

The cycling of matter and the flow of energy within ecosystems occur through interactions among different organisms and between organisms and the physical environment. All living systems need matter and energy. Matter fuels the energy-releasing chemical reactions that provide energy for life functions and provides the

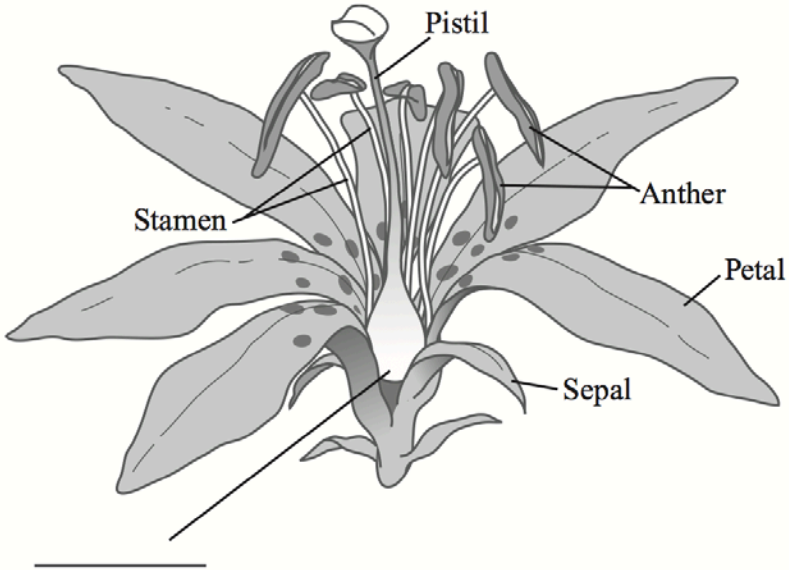
Example of DCI Match



Example CF Edit



11 The diagram below shows a flower with labels pointing to different structures. One structure has been left unlabeled.



What is the function of the unlabeled structure on this flower diagram?

A attracts pollinators
* **B** receives sperm cells
C produces food for the plant
D protects the bud before blooming

PQP Chart
Unit: Ecosystem Interactions and Dynamics

*PE (Match to DCI)				
DCI	**Phenomena**	**Driving Questions**	**Practice(s)**	**Cross Cutting Concept(s)**

Essential Question
(Critical Focus Question)
Check Sheet

Did I begin with the standards? Which standards am I going to address?
Have I determined the big idea or enduring understanding and can I write it?
Is my question looking for critical thinking and analysis?
Does my question allow for multiple ideas and/or beliefs?
Does my question encourage collaboration?
Is my question meaningful? Is it worthwhile to study for 2-4 weeks?
Is my question intellectual?
Is my question dependent on multiple reading resources to answer?
Does my question lead into my Task?
Does my question ask the learner to make a decision or to plan some action?
Is my question written in simple language?
Is my question understood by all learners?
Is my question open-ended?

Science and Engineering Practices
(Excerpted from Appendix F)

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, theory, or findings from previous investigations, or they can be 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 the 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.

Whether engaged in science or engineering, the ability to ask good questions and clearly define problems is essential for everyone.

Practice 2 Developing and Using Models

> *Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system.* (NRC Framework, 2012, p. 58)

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

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

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

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, 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 aren't 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 are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, 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 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. When possible and feasible, students should use digital tools to analyze and interpret data. Whether analyzing data for the purpose of science or engineering, it is important students present data as evidence to support their conclusions.

Practice 5 Using Mathematics and Computational Thinking

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

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

Practice 6 Constructing Explanations and Designing 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*."(NRC Framework, 2012, p. 52)
>
> *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)

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

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

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing, and improving solutions.

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 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 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. 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.

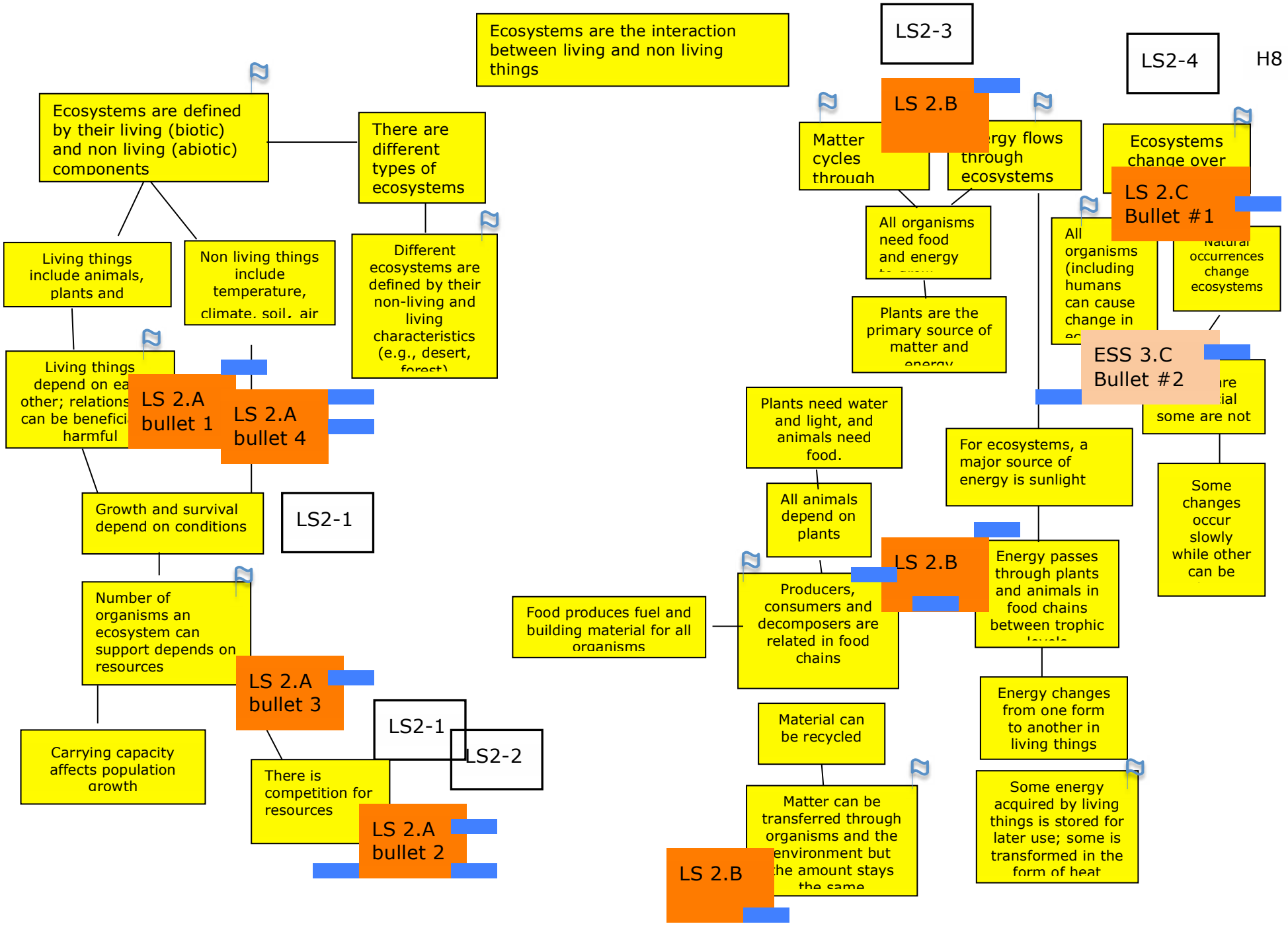
Argument in science goes beyond reaching agreements in explanations and design solutions. Whether investigating a phenomenon, testing a design, or constructing a model to provide a mechanism for an explanation, students are expected to use argumentation to listen to, compare, and evaluate competing ideas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

on their merits. 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.

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 obtain information used 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, in writing, and through extended discussions.


Ecosystems are the interaction between living and non living things
Ecosystems are defined by their living (biotic) and non living (abiotic) components
There are different types of ecosystems
Living things include animals, plants and
Non living things include temperature, climate, soil, air
Different ecosystems are defined by their non-living and living characteristics (e.g., desert, forest)
Living things depend on ea other; relations can be benefici harmful
LS 2.A bullet 1
LS 2.A bullet 4
Growth and survival depend on conditions
LS2-1
Number of organisms an ecosystem can support depends on resources
LS 2.A bullet 3
Carrying capacity affects population growth
LS2-1
LS2-2
There is competition for resources
LS 2.A bullet 2
LS2-3
LS2-4
H8
LS 2.B
Matter cycles through
rgy flows through ecosystems
Ecosystems change over
LS 2.C Bullet #1
All organisms need food and energy
All organisms (including humans can cause change in
Natural occurrences change ecosystems
Plants are the primary source of matter and energy
ESS 3.C Bullet #2
re ial some are not
Plants need water and light, and animals need food.
For ecosystems, a major source of energy is sunlight
Some changes occur slowly while other can be
All animals depend on plants
LS 2.B
Energy passes through plants and animals in food chains between trophic
Food produces fuel and building material for all organisms
Producers, consumers and decomposers are related in food chains
Energy changes from one form to another in living things
Material can be recycled
Matter can be transferred through organisms and the environment but the amount stays the same
Some energy acquired by living things is stored for later use; some is transformed in the form of heat
LS 2.B

Handout #14

PQP Chart
Unit: Ecosystem Interactions and Dynamics
Completed for one DCI

PE: MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.				
DCI	**Phenomena**	**Driving Questions**	**Practice**	**Cross Cutting Concepts**
LS2.A bullet 2 In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.	•Zebra mussels taking over CA lakes (and Great Lakes) •Kudzu growing rampantly in the south •Starlings displacing native birds •Transition of meadow or pasture to star thistle	•Why do some species flourish at the expense of other species? •Why do zebra mussels proliferate and push out other species? •Why are there so many zebra mussels in the great lakes? •Why have survived so well where other species haven't?	•Analyze & interpret data •Conduct research to find data about the zebra mussels (CCSS) •Plan and conduct investigation about different aspects of ecosystems •Argue from evidence •Construct and refine model to explain phenomenon	Possible connections Systems Energy flow and matter cycles

PQP Chart Developed by the Sacramento Area Science Project

Handout #15

science investigates cause-and-effect relationships by seeking the mechanisms that underlie them.

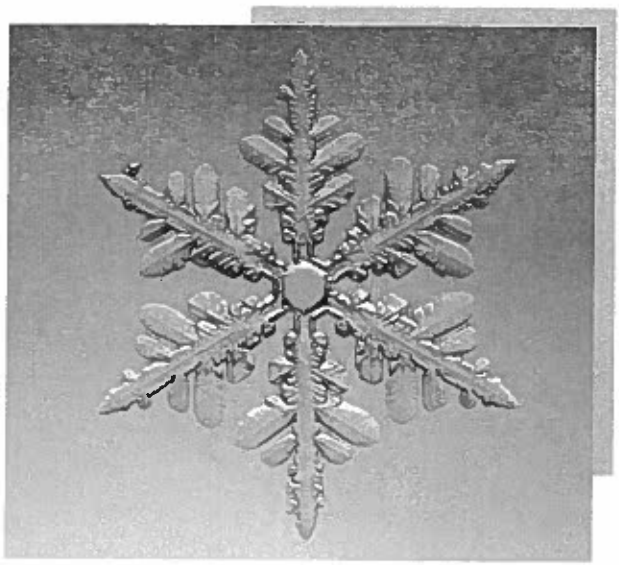
The next concept—scale, proportion, and quantity—concerns the sizes of things and the mathematical relationships among disparate elements.

The next four concepts—systems and system models, energy and matter flows, structure and function, and stability and change—are interrelated in that the first is illuminated by the other three. Each concept also stands alone as one that occurs in virtually all areas of science and is an important consideration for engineered systems as well.

The set of crosscutting concepts defined here is similar to those that appear in other standards documents, in which they have been called "unifying concepts" or "common themes" [2-4]. Regardless of the labels or organizational schemes used in these documents, all of them stress that it is important for students to come to recognize the concepts common to so many areas of science and engineering.

1 Patterns

Patterns exist everywhere—in regularly occurring shapes or structures and in repeating events and relationships. For example, patterns are discernible in the symmetry of flowers and snowflakes, the cycling of the seasons, and the repeated base pairs of DNA. Noticing patterns is often a first step to organizing and asking scientific questions about why and how the patterns occur.



One major use of pattern recognition is in classification, which depends on careful observation of similarities and differences; objects can be classified into groups on the basis of similarities of visible or microscopic features or on the basis of similarities of function. Such classification is useful in codifying relationships and organizing a multitude of objects or processes into a limited number of groups. Patterns of similarity and difference and the resulting classifications may change, depending on the scale at which a phenomenon is being observed. For example, isotopes of a given element are different—they contain different numbers of neutrons—but from the perspective of chemistry they can be classified as equivalent because they have identical patterns of chemical interaction. Once patterns and variations have been noted, they lead to questions;

Scientists seek explanations for observed patterns and for the similarity and diversity within them. Engineers often look for and analyze patterns, too.

scientists seek explanations for observed patterns and for the similarity and diversity within them. Engineers often look for and analyze patterns, too. For example, they may diagnose patterns of failure of a designed system under test in order to improve the design, or they may analyze patterns of daily and seasonal use of power to design a system that can meet the fluctuating needs.

The ways in which data are represented can facilitate pattern recognition and lead to the development of a mathematical representation, which can then be used as a tool in seeking an underlying explanation for what causes the pattern to occur. For example, biologists studying changes in population abundance of several different species in an ecosystem can notice the correlations between increases and decreases for different species by plotting all of them on the same graph and can eventually find a mathematical expression of the interdependences and food-web relationships that cause these patterns.

Progression

Human beings are good at recognizing patterns; indeed, young children begin to recognize patterns in their own lives well before coming to school. They observe, for example, that the sun and the moon follow different patterns of appearance in the sky. Once they are students, it is important for them to develop ways to recognize, classify, and record patterns in the phenomena they observe. For example, elementary students can describe and predict the patterns in the seasons of the year; they can observe and record patterns in the similarities and differences between parents and their offspring. Similarly, they can investigate the characteristics that allow classification of animal types (e.g., mammals, fish, insects), of plants (e.g., trees, shrubs, grasses), or of materials (e.g., wood, rock, metal, plastic).

These classifications will become more detailed and closer to scientific classifications in the upper elementary grades, when students should also begin to analyze patterns in rates of change—for example, the growth rates of plants under different conditions. By middle school, students can begin to relate patterns to the nature of microscopic and atomic-level structure—for example, they may note that chemical molecules contain particular ratios of different atoms. By high

school, students should recognize that different patterns may be observed at each of the scales at which a system is studied. Thus classifications used at one scale may fail or need revision when information from smaller or larger scales is introduced (e.g., classifications based on DNA comparisons versus those based on visible characteristics).

Cause and Effect: Mechanism and Prediction

Many of the most compelling and productive questions in science are about why or how something happens. Any tentative answer, or "hypothesis," that A causes B requires a model for the chain of interactions that connect A and B. For example, the notion that diseases can be transmitted by a person's touch was initially treated with skepticism by the medical profession for lack of a plausible mechanism. Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures.

Repeating patterns in nature, or events that occur together with regularity, are clues that scientists can use to start exploring causal, or cause-and-effect, relationships, which pervade all the disciplines of science and at all scales. For example, researchers investigate cause-and-effect mechanisms in the motion of a single object, specific chemical reactions, population changes in an ecosystem or a society, and the development of holes in the polar ozone layers. Any application of science, or any engineered solution to a problem, is dependent on understanding the cause-and-effect relationships between events; the quality of the application or solution often can be improved as knowledge of the relevant relationships is improved.

Identifying cause and effect may seem straightforward in simple cases, such as a bat hitting a ball, but in complex systems causation can be difficult to tease out. It may be conditional, so that A can cause B only if some other factors are in place or within a certain numerical range. For example, seeds germinate and produce plants but only when the soil is sufficiently moist and warm. Frequently, causation can be described only in a probabilistic fashion—that is, there is some likelihood that one event will lead to another, but a specific outcome cannot be guaranteed. For example, one can predict the fraction of a collection of identical

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atoms that will undergo radioactive decay in a certain period but not the exact time at which a given atom decays.

One assumption of all science and engineering is that there is a limited and universal set of fundamental physical interactions that underlie all known forces and hence are a root part of any causal chain, whether in natural or designed systems. Such "universality" means that the physical laws underlying all processes are the same everywhere and at all times; they depend on gravity, electromagnetism, or weak and strong nuclear interactions. Underlying all biological processes—the inner workings of a cell or even of a brain—are particular physical and chemical processes. At the larger scale of biological systems, the universality of life manifests itself in a common genetic code.

Causation invoked to explain larger scale systems must be consistent with the implications of what is known about smaller scale processes within the system, even though new features may emerge at large scales that cannot be predicted from knowledge of smaller scales. For example, although knowledge of atoms is not sufficient to predict the genetic code, the replication of genes must be understood as a molecular-level process. Indeed, the ability to model causal processes in complex multipart systems arises from this fact; modern computational codes incorporate relevant smaller scale relationships into the model of the larger system, integrating multiple factors in a way that goes well beyond the capacity of the human brain.

In engineering, the goal is to design a system to cause a desired effect, so cause-and-effect relationships are as much a part of engineering as of science. Indeed, the process of design is a good place to help students begin to think in terms of cause and effect, because they must understand the underlying causal relationships in order to devise and explain a design that can achieve a specified objective.

One goal of instruction about cause and effect is to encourage students to see events in the world as having understandable causes, even when these causes are beyond human control. The ability to distinguish between scientific causal claims and nonscientific causal claims is also an important goal.

Progression

In the earliest grades, as students begin to look for and analyze patterns—whether in their observations of the world or in the relationships between different quantities in data (e.g., the sizes of plants over time)—they can also begin to consider what might be causing these patterns and relationships and design tests that gather

more evidence to support or refute their ideas. By the upper elementary grades, students should have developed the habit of routinely asking about cause-and-effect relationships in the systems they are studying, particularly when something occurs that is, for them, unexpected. The questions "How did that happen?" or "Why did that happen?" should move toward "What mechanisms caused that to happen?" and "What conditions were critical for that to happen?"

In middle and high school, argumentation starting from students' own explanations of cause and effect can help them appreciate standard scientific theories that explain the causal mechanisms in the systems under study. Strategies for this type of instruction include asking students to argue from evidence when attributing an observed phenomenon to a specific cause. For example, students exploring why the population of a given species is shrinking will look for evidence in the ecosystem of factors that lead to food shortages, overpredation, or other factors in the habitat related to survival; they will provide an argument for how these and other observed changes affect the species of interest.

Scale, Proportion, and Quantity

In thinking scientifically about systems and processes, it is essential to recognize that they vary in size (e.g., cells, whales, galaxies), in time span (e.g., nanoseconds, hours, millennia), in the amount of energy flowing through them (e.g., lightbulbs, power grids, the sun), and in the relationships between the scales of these different quantities. The understanding of relative magnitude is only a starting point. As noted in *Benchmarks for Science Literacy*, "The large idea is that the way in which things work may change with scale. Different aspects of nature change at different rates with changes in scale, and so the relationships among them change, too" [4]. Appropriate understanding of scale relationships is critical as well to engineering—no structure could be conceived, much less constructed, without the engineer's precise sense of scale.

From a human perspective, one can separate three major scales at which to study science: (1) macroscopic scales that are directly observable—that is, what one can see, touch, feel, or manipulate; (2) scales that are too small or fast to observe directly; and (3) those that are too large or too slow. Objects at the atomic scale, for example, may be described with simple models, but the size of atoms and the number of atoms in a system involve magnitudes that are difficult to imagine. At the other extreme, science deals in scales that are equally difficult to imagine because they are so large—continents that move, for example, and galaxies in which the nearest star is 4 years away traveling at the speed of

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light. As size scales change, so do time scales. Thus, when considering large entities such as mountain ranges, one typically needs to consider change that occurs over long periods. Conversely, changes in a small-scale system, such as a cell, are viewed over much shorter times. However, it is important to recognize that processes that occur locally and on short time scales can have long-term and large-scale impacts as well.

In forming a concept of the very small and the very large, whether in space or time, it is important to have a sense not only of relative scale sizes but also of what concepts are meaningful at what scale. For example, the concept of solid matter is meaningless at the subatomic scale, and the concept that light takes time to travel a given distance becomes more important as one considers large distances across the universe.

Understanding scale requires some insight into measurement and an ability to think in terms of orders of magnitude—for example, to comprehend the difference between one in a hundred and a few parts per billion. At a basic level, in order to identify something as bigger or smaller than something else—and how much bigger or smaller—a student must appreciate the units used to measure it and develop a feel for quantity.

The ideas of ratio and proportionality as used in science can extend and challenge students' mathematical understanding of these concepts. To appreciate the relative magnitude of some properties or processes, it may be necessary to grasp the relationships among different types of quantities—for example, speed as the ratio of distance traveled to time taken, density as a ratio of mass to volume. This use of ratio is quite different than a ratio of numbers describing fractions of a pie. Recognition of such relationships among different quantities is a key step in forming mathematical models that interpret scientific data.

Progression

The concept of scale builds from the early grades as an essential element of understanding phenomena. Young children can begin understanding scale with objects, space, and time related to their world and with explicit scale models and maps. They may discuss relative scales—the biggest and smallest, hottest and coolest, fastest and slowest—without reference to particular units of measurement.

Typically, units of measurement are first introduced in the context of length, in which students can recognize the need for a common unit of measure—even develop their own before being introduced to standard units—through appropriately constructed experiences. Engineering design activities

involving scale diagrams and models can support students in developing facility with this important concept.

Once students become familiar with measurements of length, they can expand their understanding of scale and of the need for units that express quantities of weight, time, temperature, and other variables. They can also develop an understanding of estimation across scales and contexts, which is important for making sense of data. As students become more sophisticated, the use of estimation can help them not only to develop a sense of the size and time scales relevant to various objects, systems, and processes but also to consider whether a numerical result sounds reasonable. Students acquire the ability as well to move back and forth between models at various scales, depending on the question being considered. They should develop a sense of the powers-of-10 scales and what phenomena correspond to what scale, from the size of the nucleus of an atom to the size of the galaxy and beyond.

Well-designed instruction is needed if students are to assign meaning to the types of ratios and proportional relationships they encounter in science. Thus the ability to recognize mathematical relationships between quantities should begin developing in the early grades with students' representations of counting (e.g., leaves on a branch), comparisons of amounts (e.g., of flowers on different plants), measurements (e.g., the height of a plant), and the ordering of quantities such as number, length, and weight. Students can then explore more sophisticated mathematical representations, such as the use of graphs to represent data collected. The interpretation of these graphs may be, for example, that a plant gets bigger as time passes or that the hours of daylight decrease and increase across the months.

As students deepen their understanding of algebraic thinking, they should be able to apply it to examine their scientific data to predict the effect of a change in one variable on another, for example, or to appreciate the difference between linear growth and exponential growth. As their thinking advances, so too should their ability to recognize and apply more complex mathematical and statistical relationships in science. A sense of numerical quantity is an important part of the general "numeracy" (mathematics literacy) that is needed to interpret such relationships.

Systems and System Models

As noted in the *National Science Education Standards,* "The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience

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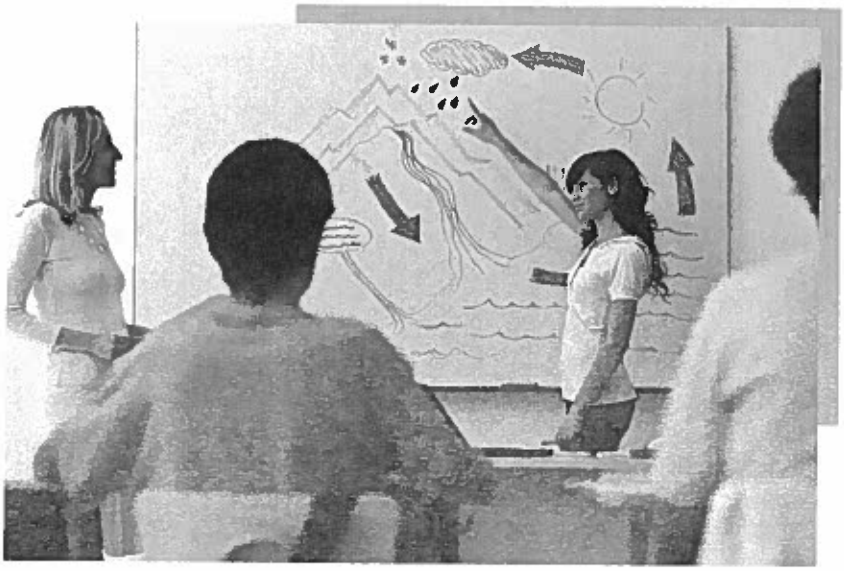
of investigation. The units of investigations can be referred to as 'systems.' A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, components, resources, flow, and feedback" [2].

Although any real system smaller than the entire universe interacts with and is dependent on other (external) systems, it is often useful to conceptually isolate a single system for study. To do this, scientists and engineers imagine an artificial boundary between the system in question and everything else. They then examine the system in detail while treating the effects of things outside the boundary as either forces acting on the system or flows of matter and energy across it—for example, the gravitational force due to Earth on a book lying on a table or the carbon dioxide expelled by an organism. Consideration of flows into and out of the system is a crucial element of system design. In the laboratory or even in field research, the extent to which a system under study can be physically isolated or external conditions controlled is an important element of the design of an investigation and interpretation of results.



Often, the parts of a system are interdependent, and each one depends on or supports the functioning of the system's other parts. Yet the properties and behavior of the whole system can be very different from those of any of its parts, and large systems may have emergent properties, such as the shape of a tree, that cannot be predicted in detail from knowledge about the components and their interactions. Things viewed as subsystems at one scale may themselves be viewed as whole systems at a smaller scale. For example, the circulatory system can be seen as an entity in itself or as a subsystem of the entire human body; a molecule can be studied as a stable configuration of atoms but also as a subsystem of a cell or a gas.

An explicit model of a system under study can be a useful tool not only for gaining understanding of the system but also for conveying it to others. Models of a system can range in complexity from lists and simple sketches to detailed computer simulations or functioning prototypes.

Models can be valuable in predicting a system's behaviors or in diagnosing problems or failures in its functioning, regardless of what type of system is being examined. A good system model for use in developing scientific explanations or engineering designs must specify not only the parts, or subsystems, of the system but also how they interact with one another. It must also specify the boundary of the system being modeled, delineating what is included in the model and what is to be treated as external. In a simple mechanical system, interactions among the parts are describable in terms of forces among them that cause changes in motion or physical stresses. In more complex systems, it is not always possible or useful to consider interactions at this detailed mechanical level, yet it is equally important to ask what interactions are occurring (e.g., predator-prey relationships in an ecosystem) and to recognize that they all involve transfers of energy, matter, and (in some cases) information among parts of the system.

Any model of a system incorporates assumptions and approximations; the key is to be aware of what they are and how they affect the model's reliability and precision. Predictions may be reliable but not precise or, worse, precise but not reliable; the degree of reliability and precision needed depends on the use to which the model will be put.

Progression

As science instruction progresses, so too should students' ability to analyze and model more complex systems and to use a broader variety of representations to explicate what they model. Their thinking about systems in terms of component parts and their interactions, as well as in terms of inputs, outputs, and processes, gives students a way to organize their knowledge of a system, to generate questions that can lead to enhanced understanding, to test aspects of their model of the system, and, eventually, to refine their model.

Starting in the earliest grades, students should be asked to express their thinking with drawings or diagrams and with written or oral descriptions. They should describe objects or organisms in terms of their parts and the roles those parts play in the functioning of the object or organism, and they should note relationships between the parts. Students should also be asked to create plans—for example, to draw or write a set of instructions for building something—that another child can follow. Such experiences help them develop the concept of a model of a system and realize the importance of representing one's ideas so that others can understand and use them.

As students progress, their models should move beyond simple renderings or maps and begin to incorporate and make explicit the invisible features of a system, such as interactions, energy flows, or matter transfers. Mathematical ideas, such as ratios and simple graphs, should be seen as tools for making more definitive models; eventually, students' models should incorporate a range of mathematical relationships among variables (at a level appropriate for grade-level mathematics) and some analysis of the patterns of those relationships. By high school, students should also be able to identify the assumptions and approximations that have been built into a model and discuss how they limit the precision and reliability of its predictions.

Instruction should also include discussion of the interactions *within* a system. As understanding deepens, students can move from a vague notion of interaction as one thing affecting another to more explicit realizations of a system's physical, chemical, biological, and social interactions and of their relative importance for the question at hand. Students' ideas about the interactions in a system and the explication of such interactions in their models should become more sophisticated in parallel with their understanding of the microscopic world (atoms, molecules, biological cells, microbes) and with their ability to interpret and use more complex mathematical relationships.

Modeling is also a tool that students can use in gauging their own knowledge and clarifying their questions about a system. Student-developed models may reveal problems or progress in their conceptions of the system, just as scientists' models do. Teaching students to explicitly craft and present their models in diagrams, words, and, eventually, in mathematical relationships serves three purposes. It supports them in clarifying their ideas and explanations and in considering any inherent contradictions; it allows other students the opportunity to critique and suggest revisions for the model; and it offers the teacher insights into those aspects of each student's understanding that are well founded and those that could benefit from further instructional attention. Likewise in engineering projects, developing systems thinking and system models supports critical steps in developing, sharing, testing, and refining design ideas.

Energy and Matter: Flows, Cycles, and Conservation

One of the great achievements of science is the recognition that, in any system, certain conserved quantities can change only through transfers into or out of the system. Such laws of conservation provide limits on what can occur in a system, whether human built or natural. This section focuses on two such quantities,

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matter and energy, whose conservation has important implications for the disciplines of science in this framework. The supply of energy and of each needed chemical element restricts a system's operation—for example, without inputs of energy (sunlight) and matter (carbon dioxide and water), a plant cannot grow. Hence, it is very informative to track the transfers of matter and energy within, into, or out of any system under study.

In many systems there also are cycles of various types. In some cases, the most readily observable cycling may be of matter—for example, water going back and forth between Earth's atmosphere and its surface and subsurface reservoirs. Any such cycle of matter also involves associated energy transfers at each stage, so to fully understand the water cycle, one must model not only how water moves between parts of the system but also the energy transfer mechanisms that are critical for that motion.

Consideration of energy and matter inputs, outputs, and flows or transfers within a system or process are equally important for engineering. A major goal in design is to maximize certain types of energy output while minimizing others, in order to minimize the energy inputs needed to achieve a desired task.

The ability to examine, characterize, and model the transfers and cycles of matter and energy is a tool that students can use across virtually all areas of science and engineering. And studying the *interactions* between matter and energy supports students in developing increasingly sophisticated conceptions of their role in any system. However, for this development to occur, there needs to be a common use of language about energy and matter across the disciplines in science instruction.

Progression

The core ideas of matter and energy and their development across the grade bands are spelled out in detail in Chapter 5. What is added in this crosscutting discussion is recognition that an understanding of these core ideas can be informative in examining systems in life science, earth and space science, and engineering contexts. Young children are likely to have difficulty studying the concept of

energy in depth—everyday language surrounding energy contains many shortcuts that lead to misunderstandings. For this reason, the concept is not developed at all in K-2 and only very generally in grades 3-5. Instead, the elementary grades focus on recognition of conservation of matter and of the flow of matter into, out of, and within systems under study. The role of energy transfers in conjunction with these flows is not introduced until the middle grades and only fully developed by high school.

Clearly, incorrect beliefs—such as the perception that food or fuel is a form of energy—would lead to elementary grade students' misunderstanding of the nature of energy. Hence, although the necessity for food or fuel can be discussed, the language of energy needs to be used with care so as not to further establish such misconceptions. By middle school, a more precise idea of energy—for example, the understanding that food or fuel undergoes a chemical reaction with oxygen that releases stored energy—can emerge. The common misconceptions can be addressed with targeted instructional interventions (including student-led investigations), and appropriate terminology can be used in discussing energy across the disciplines.

Matter transfers are less fraught in this respect, but the idea of atoms is not introduced with any specificity until middle school. Thus, at the level of grades 3-5, matter flows and cycles can be tracked only in terms of the weight of the substances before and after a process occurs, such as sugar dissolving in water. Mass/weight distinctions and the idea of atoms and their conservation (except in nuclear processes) are taught in grades 6-8, with nuclear substructure and the related conservation laws for nuclear processes introduced in grades 9-12.

Structure and Function

As expressed by the National Research Council in 1996 and reiterated by the College Board in 2009, "Form and function are complementary aspects of objects, organisms, and systems in the natural and designed world. . . . Understanding of form and function applies to different levels of organization. Function can be explained in terms of form and form can be explained in terms of function" [2, 3].

The functioning of natural and built systems alike depends on the shapes and relationships of certain key parts as well as on the properties of the materials from which they are made. A sense of scale is necessary in order to know what properties and what aspects of shape or material are relevant at a particular magnitude or in investigating particular phenomena—that is, the selection of an appropriate scale depends on the question being asked. For example, the substructures of molecules

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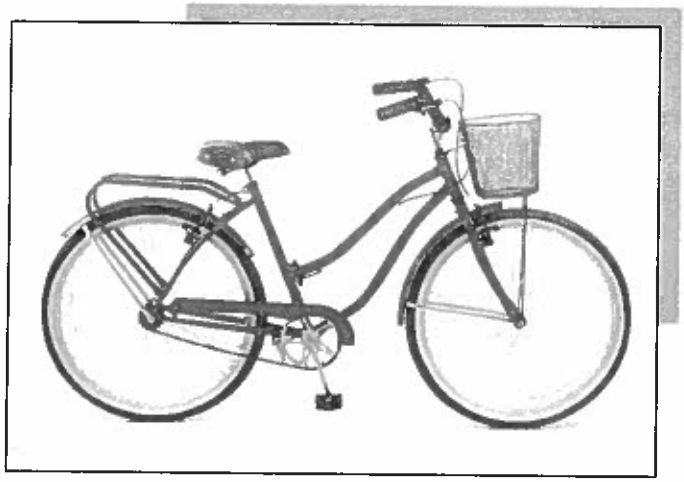
are not particularly important in understanding the phenomenon of pressure, but they are relevant to understanding why the ratio between temperature and pressure at constant volume is different for different substances.

Similarly, understanding how a bicycle works is best addressed by examining the structures and their functions at the scale of, say, the frame, wheels, and pedals. However, building a lighter bicycle may require knowledge of the properties (such as rigidity and hardness) of the materials needed for specific parts of the bicycle. In that way, the builder can seek less dense materials with appropriate properties; this pursuit may lead in turn to an examination of the atomic-scale structure of candidate materials. As a result, new parts with the desired properties, possibly made of new materials, can be designed and fabricated.

Progression

Exploration of the relationship between structure and function can begin in the early grades through investigations of accessible and visible systems in the natural and human-built world. For example, children explore how shape and stability are related for a variety of structures (e.g., a bridge's diagonal brace) or purposes (e.g., different animals get their food using different parts of their bodies). As children move through the elementary grades, they progress to understanding the relationships of structure and mechanical function (e.g., wheels and axles, gears). For upper-elementary students, the concept of matter having a substructure at a scale too small to see is related to properties of materials; for example, a model of a gas as a collection of moving particles (not further defined) may be related to observed properties of gases. Upper-elementary students can also examine more complex structures, such as subsystems of the human body, and consider the relationship of the shapes of the parts to their functions. By the middle grades, students begin to visualize, model, and apply their understanding of structure and function to more complex or less easily observable systems and processes (e.g., the structure of water and salt molecules and solubility, Earth's plate tectonics). For students in the middle grades, the concept of matter having a submicroscopic structure is related to properties of materials; for example, a model based on atoms and/or molecules



and their motions may be used to explain the properties of solids, liquids, and gases or the evaporation and condensation of water.

As students develop their understanding of the relationships between structure and function, they should begin to apply this knowledge when investigating phenomena that are unfamiliar to them. They recognize that often the first step in deciphering how a system works is to examine in detail what it is made of and the shapes of its parts. In building something—say, a mechanical system—they likewise apply relationships of structure and function as critical elements of successful designs.

Stability and Change

"Much of science and mathematics has to do with understanding how change occurs in nature and in social and technological systems, and much of technology has to do with creating and controlling change," according to the American Association for the Advancement of Science. "Constancy, often in the midst of change, is also the subject of intense study in science" [4].

Stability denotes a condition in which some aspects of a system are unchanging, at least at the scale of observation. Stability means that a small disturbance will fade away—that is, the system will stay in, or return to, the stable condition. Such stability can take different forms, with the simplest being a static equilibrium, such as a ladder leaning on a wall. By contrast, a system with steady inflows and outflows (i.e., constant conditions) is said to be in dynamic equilibrium. For example, a dam may be at a constant level with steady quantities of water coming in and out. Increase the inflow, and a new equilibrium level will eventually be reached if the outflow increases as well. At extreme flows, other factors may cause *dis*equilibrium; for example, at a low-enough inflow, evaporation may cause the level of the water to continually drop. Likewise, a fluid at a constant temperature can be in a steady state with constant chemical composition even though chemical reactions that change the composition in two opposite directions are occurring within it; change the temperature and it will reach a new steady state with a different composition.

A repeating pattern of cyclic change—such as the moon orbiting Earth—can also be seen as a stable situation, even though it is clearly not static. Such a system has constant aspects, however, such as the distance from Earth to the moon, the period of its orbit, and the pattern of phases seen over time.

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important to understanding natural systems as well. A feedback loop is any mechanism in which a condition triggers some action that causes a change in that same condition, such as the temperature of a room triggering the thermostatic control that turns the room's heater on or off. Feedback can stabilize a system (negative feedback—a thermostat in a cooling room triggers heating, but only until a particular temperature range is reached) or destabilize a system (positive feedback—a fire releases heat, which triggers the burning of more fuel, which causes the fire to continue to grow).

A system can be stable on a small time scale, but on a larger time scale it may be seen to be changing. For example, when looking at a living organism over the course of an hour or a day, it may maintain stability; over longer periods, the organism grows, ages, and eventually dies. For the development of larger systems, such as the variety of living species inhabiting Earth or the formation of a galaxy, the relevant time scales may be very long indeed; such processes occur over millions or even billions of years.

When studying a system's patterns of change over time, it is also important to examine what is unchanging. Understanding the feedback mechanisms that regulate the system's stability or that drive its instability provides insight into how the system may operate under various conditions. These mechanisms are important to evaluate when comparing different design options that address a particular problem.

Any system has a range of conditions under which it can operate in a stable fashion, as well as conditions under which it cannot function. For example, a particular living organism can survive only within a certain range of temperatures, and outside that span it will die. Thus elucidating what range of conditions can lead to a system's stable operation and what changes would destabilize it (and in what ways) is an important goal.

Note that stability is always a balance of competing effects; a small change in conditions or in a single component of the system can lead to runaway changes in the system if compensatory mechanisms are absent. Nevertheless, students typically begin with an idea of equilibrium as a static situation, and they interpret a lack of change in the system as an indication that nothing is happening. Thus they need guidance to begin to appreciate that stability can be the result of multiple opposing forces; they should be taught to identify the invisible forces—to appreciate the dynamic equilibrium—in a seemingly static situation, even one as simple as a book lying on a table.

An understanding of dynamic equilibrium is crucial to understanding the major issues in any complex system—for example, population dynamics in an ecosystem or the relationship between the level of atmospheric carbon dioxide and Earth's average temperature. Dynamic equilibrium is an equally important concept for understanding the physical forces in matter. Stable matter is a system of atoms in dynamic equilibrium.

For example, the stability of the book lying on the table depends on the fact that minute distortions of the table caused by the book's downward push on the table in turn cause changes in the positions of the table's atoms. These changes then alter the forces between those atoms, which lead to changes in the upward force on the book exerted by the table. The book continues to distort the table until the table's upward force on the book exactly balances the downward pull of gravity on the book. Place a heavy enough item on the table, however, and stability is not possible; the distortions of matter within the table continue to the macroscopic scale, and it collapses under the weight. Such seemingly simple, explicit, and visible examples of how change in some factor produces changes in the system can help to establish a mental model of dynamic equilibrium useful for thinking about more complex systems.

Understanding long-term changes—for example, the evolution of the diversity of species, the surface of Earth, or the structure of the universe—requires a sense of the requisite time scales for such changes to develop. Long time scales can be difficult for students to grasp, however. Part of their understanding should grow from an appreciation of how scientists investigate the nature of these processes—through the interplay of evidence and system modeling. Student-developed models that use comparative time scales can also be helpful; for example, if the history of Earth is scaled to 1 year (instead of the absolute measures in eons), students gain a more intuitive understanding of the relative durations of periods in the planet's evolution.

Progression

Even very young children begin to explore stability (as they build objects with blocks or climb on a wall) and change (as they note their own growth or that of a plant). The role of instruction in the early grades is to help students to develop some language for these concepts and apply it appropriately across multiple examples, so that they can ask such questions as "What could I change to make this balance better?" or "How fast did the plants grow?" One of the goals of discussion of stability and change in the elementary grades should

be the recognition that it can be as important to ask why something does not change as why it does.

Likewise, students should come to recognize that both the regularities of a pattern over time and its variability are issues for which explanations can be sought. Examining these questions in different contexts (e.g., a model ecosystem such as a terrarium, the local weather, a design for a bridge) broadens students' understanding that stability and change are related and that a good model for a system must be able to offer explanations for both.

In middle school, as student's understanding of matter progresses to the atomic scale, so too should their models and their explanations of stability and change. Furthermore, they can begin to appreciate more subtle or conditional situations and the need for feedback to maintain stability. At the high school level, students can model more complex systems and comprehend more subtle issues of stability or of sudden or gradual change over time. Students at this level should also recognize that much of science deals with constructing historical explanations of how things evolved to be the way they are today, which involves modeling rates of change and conditions under which the system is stable or changes gradually, as well as explanations of any sudden change.

INTERCONNECTIONS BETWEEN CROSSCUTTING CONCEPTS AND DISCIPLINARY CORE IDEAS

Students' understanding of these crosscutting concepts should be reinforced by repeated use of them in the context of instruction in the disciplinary core ideas presented in Chapters 5-8. In turn, the crosscutting concepts can provide a connective structure that supports students' understanding of sciences as disciplines and that facilitates students' comprehension of the phenomena under study in particular disciplines. Thus these crosscutting concepts should not be taught in isolation from the examples provided in the disciplinary context. Moreover, use of a common language for these concepts across disciplines will help students to recognize that the same concept is relevant across different contexts.

at a later stage, to test a physical prototype. Both scientists and engineers use their models—including sketches, diagrams, mathematical relationships, simulations, and physical models—to make predictions about the likely behavior of a system, and they then collect data to evaluate the predictions and possibly revise the models as a result.

Between and within these two spheres of activity is the practice of evaluation, represented by the middle space. Here is an iterative process that repeats at every step of the work. Critical thinking is required, whether in developing and refining an idea (an explanation or a design) or in conducting an investigation. The dominant activities in this sphere are argumentation and critique, which often lead to further experiments and observations or to changes in proposed models, explanations, or designs. Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design.

In reality, scientists and engineers move, fluidly and iteratively, back and forth among these three spheres of activity, and they conduct activities that might involve two or even all three of the modes at once. The function of Figure 3-1 is therefore solely to offer a scheme that helps identify the function, significance, range, and diversity of practices embedded in the work of scientists and engineers. Although admittedly a simplification, the figure does identify three overarching categories of practices and shows how they interact.

How Engineering and Science Differ

Engineering and science are similar in that both involve creative processes, and neither uses just one method. And just as scientific investigation has been defined in different ways, engineering design has been described in various ways. However, there is widespread agreement on the broad outlines of the engineering design process [24, 25].

Like scientific investigations, engineering design is both iterative and systematic. It is iterative in that each new version of the design is tested and then modified, based on what has been learned up to that point. It is systematic in that a number of characteristic steps must be undertaken. One step is identifying the problem and defining specifications and constraints. Another step is generating ideas for how to solve the problem; engineers often use research and group

sessions (e.g., "brainstorming") to come up with a range of solutions and design alternatives for further development. Yet another step is the testing of potential solutions through the building and testing of physical or mathematical models and prototypes, all of which provide valuable data that cannot be obtained in any other way. With data in hand, the engineer can analyze how well the various solutions meet the given specifications and constraints and then evaluate what is needed to improve the leading design or devise a better one.

In contrast, scientific studies may or may not be driven by any immediate practical application. On one hand, certain kinds of scientific research, such as that which led to Pasteur's fundamental contributions to the germ theory of disease, were undertaken for practical purposes and resulted in important new technologies, including vaccination for anthrax and rabies and the pasteurization of milk to prevent spoilage. On the other hand, many scientific studies, such as the search for the planets orbiting distant stars, are driven by curiosity and undertaken with the aim of answering a question about the world or understanding an

Students' opportunities to immerse themselves in these practices and to explore why they are central to science and engineering are critical to appreciating the skill of the expert and the nature of his or her enterprise.

observed pattern. For science, developing such an explanation constitutes success in and of itself, regardless of whether it has an immediate practical application; the goal of science is to develop a set of coherent and mutually consistent theoretical descriptions of the world that can provide explanations over a wide range of phenomena, For engineering, however, success is measured by the extent to which a human need or want has been addressed.

Both scientists and engineers engage in argumentation, but they do so with different goals. In engineering, the goal of argumentation is to evaluate prospective designs and then produce the most effective design for meeting the specifications and constraints. This optimization process typically involves trade-offs between competing goals, with the consequence that there is never just one "correct" solution to a design challenge. Instead, there are a number of possible solutions, and choosing among them inevitably involves personal as well as technical and cost considerations. Moreover, the continual arrival of new technologies enables new solutions.

In contrast, theories in science must meet a very different set of criteria, such as parsimony (a preference for simpler solutions) and explanatory coherence (essentially how well any new theory provides explanations of phenomena that fit with observations and allow predictions or inferences about the past to be made). Moreover, the aim of science is to find a single coherent and comprehensive theory for a range of related phenomena. Multiple competing explanations are regarded as unsatisfactory and, if possible, the contradictions they contain must be resolved through more data, which enable either the selection of the best available explanation or the development of a new and more comprehensive theory for the phenomena in question.

Although we do not expect K-12 students to be able to develop new scientific theories, we do expect that they can develop theory-based models and argue using them, in conjunction with evidence from observations, to develop explanations. Indeed, developing evidence-based models, arguments, and explanations is key to both developing and demonstrating understanding of an accepted scientific viewpoint.

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."

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, theory, or findings from previous investigations, or they can be 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 the 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.

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 summarizes what students should be able to do by the end of each grade band. Each of the examples of asking questions below leads to students engaging in other scientific practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Asking questions and defining problems in K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. • Ask questions based on observations to find more information about the natural and/or designed world(s). • Ask and/or identify questions that can be answered by an investigation. • 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 3–5 builds on K–2 experiences and progresses to specifying qualitative relationships. • Ask questions about what would happen if a variable is changed. • 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. • 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.	Asking questions and defining problems in 6–8 builds on K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. • Ask questions ○ that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. ○ to identify and/or clarify evidence and/or the premise(s) of an argument. ○ to determine relationships between independent and dependent variables and relationships in models. ○ to clarify and/or refine a model, an explanation, or an engineering problem. ○ that require sufficient and appropriate empirical evidence to answer. ○ that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Ask questions ○ that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. ○ that arise from examining models or a theory, to clarify and/or seek additional information and relationships. ○ to determine relationships, including quantitative relationships, between independent and dependent variables. ○ to clarify and refine a model, an explanation, or an engineering problem. • Evaluate a question to determine if it is testable and

		appropriate, frame a hypothesis based on observations and scientific principles. ○ that challenge the premise(s) of an argument or the interpretation of a data set. • 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.	relevant. • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. • Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or 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 models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations.

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

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

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions. • 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 a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). • Develop a simple model based on evidence to represent a proposed object or tool.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Identify limitations of models. • 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 solution. • Develop and/or use models to describe and/or predict phenomena. • 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.	Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Evaluate limitations of a model for a proposed object or tool. • 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 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. • 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.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. • Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

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, 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 aren't 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 are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, 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.

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, 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. • Evaluate different ways of observing and/or measuring a phenomenon to determine which way can answer a question. • Make observations (firsthand or from media) and/or measurements to collect data that can be used to make comparisons. • Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it	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. • 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. • Evaluate appropriate methods and/or tools for collecting data. • 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	Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or solutions. • 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. • Evaluate the accuracy of various methods for collecting data. • Collect data to produce data to serve as the basis for evidence to answer scientific questions or test	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data.

solves a problem or meets a goal. • Make predictions based on prior experiences.	determine which better meets criteria for success.	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.

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 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. When possible and feasible, students should use digital tools to analyze and interpret data. Whether analyzing data for the purpose of science or engineering, it is important students present data 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. • Record information (observations, thoughts, and ideas). • Use and share pictures, drawings, and/or writings of observations. • Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems. • Compare predictions (based on prior experiences) to what occurred (observable events). • Analyze data from tests of an object or tool to determine if it works as intended.	Analyzing data in 3–5 builds on 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. • Represent data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships. • Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation. • Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings. • 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.	Analyzing data in 6–8 builds on 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. • 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. • Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, 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). • Analyze and interpret data to determine similarities and differences in findings. • 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 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. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

Practice 5 Using Mathematics and Computational Thinking

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

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

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Mathematical and computational thinking in K–2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world(s). • Decide when to use qualitative vs. quantitative data. • Use counting and numbers to identify and describe patterns in the natural and designed world(s). • Describe, measure, and/or 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 in 3–5 builds on K–2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions. • Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success. • Organize simple data sets to reveal patterns that suggest relationships. • Describe, measure, estimate, and/or graph quantities (e.g., area, volume, weight, time) to address scientific and engineering questions and problems. • Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.	Mathematical and computational thinking in 6–8 builds on K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. • Use mathematical representations to describe and/or support scientific conclusions and design solutions. • Create algorithms (a series of ordered steps) to solve a problem. • Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, 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.	Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. • Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).

Practice 6 Constructing Explanations and Designing Solutions

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

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

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

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

> *Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.*
>
> *In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.* (NRC Framework, 2012, p. 68-69)

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions. • Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. • Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. • Generate and/or compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. • Construct an explanation of observed relationships (e.g., the distribution of plants in the back yard). • Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how	Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • 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. • 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, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events. • Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.	Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

	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.

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 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 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. 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. 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. 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.

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(s). • 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. • Listen actively to arguments to indicate agreement or disagreement based on evidence, and/or to retell the main points of the argument. • Construct an argument with evidence to support a claim. • Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence.	Engaging in argument from evidence in 3–5 builds on 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(s). • 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. • Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing specific questions. • Construct and/or support an argument with evidence, data, and/or a model. • Use data to evaluate claims about cause and effect. • 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 on 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(s). • Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • 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. • 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 on 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(s). Arguments may also come from current scientific or historical episodes in science. • Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions. • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. • Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. • Evaluate competing design solutions to a real-world problem based on scientific ideas and principles,

		• Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	empirical evidence, and/or 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 obtain information used 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, 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 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 world(s). • Describe how specific images (e.g., a diagram showing how a machine works) support a scientific or engineering idea. • 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. • 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.	Obtaining, evaluating, and communicating information in 3–5 builds on K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods. • 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 across complex texts and/or other reliable media to support the engagement in other scientific and/or engineering practices. • Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support the engagement in other scientific and/or engineering practices. • Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem. • Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.	Obtaining, evaluating, and communicating information in 6–8 builds on K–5 experiences and progresses to evaluating the merit and validity of ideas and methods. • 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 world(s). • 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. • Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and 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. • Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences 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 and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. • Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).

Handout #18

REFLECTING ON THE PRACTICES

Science has been enormously successful in extending humanity's knowledge of the world and, indeed transforming it. Understanding how science has achieved this success and the techniques that it uses is an essential part of any science education. Although there is no universal agreement about teaching the nature of science, there is a strong consensus about characteristics of the scientific enterprise that should be understood by an educated citizen [41-43]. For example, the notion that there is a single scientific method of observation, hypothesis, deduction, and conclusion—a myth perpetuated to this day by many textbooks—is fundamentally wrong [44]. Scientists do use deductive reasoning, but they also search for patterns, classify different objects, make generalizations from repeated observations, and engage in a process of making inferences as to what might be the best explanation. Thus the picture of scientific reasoning is richer, more complex, and more diverse than the image of a linear and unitary scientific method would suggest [45].

What engages *all* scientists, however, is a process of critique and argumentation. Because they examine each other's ideas and look for flaws, controversy and debate among scientists are normal occurrences, neither exceptional nor extraordinary. Moreover, science has established a formal mechanism of peer review for establishing the credibility of any individual scientist's work. The ideas that survive this process of review and criticism are the ones that become well established in the scientific community.

Our view is that the opportunity for students to learn the basic set of practices outlined in this chapter is also an opportunity to have them stand back and reflect on how these practices contribute to the accumulation of scientific knowledge. For example, students need to see that the construction of models is a major means of acquiring new understanding; that these models identify key features and are akin to a map, rather than a literal representation of reality [13]; and that the great achievement of science is a core set of explanatory theories that have wide application [46].

Understanding how science functions requires a synthesis of content knowledge, procedural knowledge, and epistemic knowledge. Procedural knowledge refers to the methods that scientists use to ensure that their findings are valid and reliable. It includes an understanding of the importance and appropriate use of controls, double-blind trials, and other procedures (such as methods to reduce error) used by science. As such, much of it is specific to the domain

and can only be learned within science. Procedural knowledge has also been called "concepts of evidence" [47].

Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim and be able to readily distinguish between them. An education in science should show that new scientific ideas are acts of imagination, commonly created these days through collaborative efforts of groups of scientists whose critiques and arguments are fundamental to establishing which ideas are worthy of pursuing further. Ideas often survive because they are coherent with what is already known, and they either explain the unexplained, explain more observations, or explain in a simpler and more elegant manner.

Science is replete with ideas that once seemed promising but have not withstood the test of time, such as the concept of the "ether" or the *vis vitalis* (the "vital force" of life). Thus any new idea is initially tentative, but over time, as it survives repeated testing, it can acquire the status of a fact—a piece of knowledge that is unquestioned and uncontested, such as the existence of atoms. Scientists use the resulting theories and the models that represent them to explain and predict causal relationships. When the theory is well tested, its predictions are reliable, permitting the application of science to technologies and a wide variety of policy decisions. In other words, science is not a miscellany of facts but a coherent body of knowledge that has been hard won and that serves as a powerful tool.

Engagement in modeling and in critical and evidence-based argumentation invites and encourages students to reflect on the status of their own knowledge and their understanding of how science works. And as they involve themselves in the practices of science and come to appreciate its basic nature, their level of sophistication in understanding how any given practice contributes to the scientific enterprise can continue to develop across all grade levels.