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 to increase (e.g. it is far more likely for a broken glass to scatter than for scattered bits to assemble themselves into a whole glass). In some cases, order seems to emerge from chaos, as when a plant sprouts, or a tornado appears amidst scattered storm clouds. It is in such examples that patterns exist and the beauty of nature is found. "Noticing patterns is often a first step to organizing phenomena and asking scientific questions about why and how the patterns occur." (p. 85)

"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. 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." (page 85-86)

Patterns figure prominently in the science and engineering practice of "Analyzing and Interpreting Data." Recognizing patterns is a large part of working with data. Students might look at geographical patterns on a map, plot data values on a chart or graph, or visually inspect the appearance of an organism or mineral. The crosscutting concept of patterns is also strongly associated with the practice of "Using Mathematics and Computational Thinking." It is often the case that patterns are identified best using mathematical concepts. As Richard Feynman said, "To those who do not know mathematics it is difficult to get across a real feeling as to the beauty, the deepest beauty, of nature. If you want to learn about nature, to appreciate nature, it is necessary to understand the language that she speaks in."

The human brain is remarkably adept at identifying patterns, and students progressively build upon this innate ability throughout their school experiences. The following table lists the guidelines used by the writing team for how this progression plays out across K-12, with examples of performance expectations drawn from the NGSS.

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, children recognize that patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.	1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted.
In grades 3-5, students identify similarities and differences in order to sort and classify natural objects and designed products. They identify patterns related to time, including simple rates of change and cycles, and to use these patterns to make predictions.	4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.
In grades 6-8, students recognize that macroscopic patterns are related to the nature of microscopic and atomic-level structure. They identify patterns in rates of change and other numerical relationships that provide information about natural and human designed systems. They use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data.	MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.

In grades 9-12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system.	HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

2. Cause and effect is often the next step in science, after a discovery of patterns or events that occur together with regularity. A search for the underlying cause of a phenomenon has sparked some of the most compelling and productive scientific investigations. "Any tentative answer, or 'hypothesis,' that A causes B requires a model or mechanism 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." (p. 87)

"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." (p.88)

When students perform the practice of "Planning and Carrying Out Investigations," they often address cause and effect. At early ages, this involves "doing" something to the system of study and then watching to see what happens. At later ages, experiments are set up to test the sensitivity of the parameters involved, and this is accomplished by making a change (cause) to a single component of a system and examining, and often quantifying, the result (effect). Cause and effect is also closely associated with the practice of "Engaging in Argument from Evidence." In scientific practice, deducing the cause of an effect is often difficult, so multiple hypotheses may coexist. For example, though the occurrence (effect) of historical mass extinctions of organisms, such as the dinosaurs, is well established, the reason or reasons for the extinctions (cause) are still debated, and scientists develop and debate their arguments based on different forms of evidence. When students engage in scientific argumentation, it is often centered about identifying the causes of an effect.

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students learn that events have causes that generate observable patterns. They design simple tests to gather evidence to support or refute their own ideas about causes.	1-PS4-3. Plan and conduct an investigation to determine the effect of placing objects made with different materials in the path of a beam of light.
In grades 3-5, students routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.	4-ESS2-1. Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

In grades 6-8, students classify relationships as causal or correlational, and recognize that correlation does not necessarily imply causation. They use cause and effect relationships to predict phenomena in natural or designed systems. They also understand that phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
In grades 9-12, students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.	HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

3. Scale, Proportion and Quantity are important in both science and engineering. These are fundamental assessments of dimension that form the foundation of observations about nature. Before an analysis of function or process can be made (the *how* or *why*), it is necessary to identify the *what*. These concepts are the starting point for scientific understanding, whether it is of a total system or its individual components. Any student who has ever played the game "twenty questions" understands this inherently, asking questions such as, "Is it bigger than a bread box?" in order to first determine the object's size.

An understanding of scale involves not only understanding systems and processes vary in size, time span, and energy, but also different mechanisms operate at different scales. In engineering, "no structure could be conceived, much less constructed, without the engineer's precise sense of scale... 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." (p. 90)

"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." (p. 90)

The crosscutting concept of Scale, Proportion, and Quantity figures prominently in the practices of "Using Mathematics and Computational Thinking" and in "Analyzing and Interpreting Data." This concept addresses taking measurements of structures and phenomena, and these fundamental observations are usually obtained, analyzed, and interpreted quantitatively. This crosscutting concept also figures prominently in the practice of "Developing and Using Models." Scale and proportion are often best understood using models. For example, the relative scales of objects in the solar system or of the components of an atom are difficult to comprehend mathematically (because the numbers involved are either so large or so small), but visual or conceptual models make them much more understandable (e.g., if the solar system were the size of a penny, the Milky Way galaxy would be the size of Texas).

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students use relative scales (e.g., bigger and smaller; hotter and colder; faster and slower) to describe objects. They use standard units to measure length.	
In grades 3-5, students recognize natural objects and observable phenomena exist from the very small to the immensely large. They use standard units to measure and describe physical quantities such as weight, time, temperature, and volume.	5-ESS1-1. Support an argument that the apparent brightness of the sun and stars is due to their relative distances from Earth.
In grades 6-8, students observe time, space, and energy phenomena at various scales using models to study systems that are too large or too small. They understand phenomena observed at one scale may not be observable at another scale, and the function of natural and designed systems may change with scale. They use proportional relationships (e.g., speed as the ratio of distance traveled to time taken) to gather information about the magnitude of properties and processes. They represent scientific relationships through the use of algebraic expressions and equations.	MS-LS1-1. Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.
In grades 9-12, students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).	HS-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

4. Systems and System Models are useful in science and engineering because the world is complex, so it is helpful to isolate a single system and construct a simplified model of it. "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…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." (p. 92)

"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… 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." (p. 93)

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students understand objects and organisms can be described in terms of their parts; and systems in the natural and designed world have parts that work together.	K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
In grades 3-5, students understand that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. They can also describe a system in terms of its components and their interactions.	3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.
In grades 6-8, students can understand that systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. They can use models to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. They can also learn that models are limited in that they only represent certain aspects of the system under study.	MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
In grades 9-12, students can investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models. They can also design systems to do specific tasks.	HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

5. Energy and Matter are essential concepts in all disciplines of science and engineering, often in connection with systems. "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." (p. 95)

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students observe objects may break into smaller pieces, be put together into larger pieces, or change shapes.	2-PS1-3. Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object.
In grades 3-5, students learn matter is made of particles and energy can be transferred in various ways and between objects. Students observe the conservation of matter by tracking matter flows and cycles before and after processes and recognizing the total weight of substances does not change.	5-LS1-1. Support an argument that plants get the materials they need for growth chiefly from air and water.
In grades 6-8, students learn matter is conserved because atoms are conserved in physical and chemical processes. They also learn within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter. Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). The transfer of energy can be tracked as energy flows through a designed or natural system.	MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
In grades 9-12, students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.	HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

6. Structure and Function are complementary properties. "The shape and stability of structures of natural and designed objects are related to their function(s). 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 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." (p. 96-97)

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students observe the shape and stability of structures of natural and designed objects are related to their function(s).	2-LS2-2. Develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants
In grades 3-5, students learn different materials have different substructures, which can sometimes be observed; and substructures have shapes and parts that serve functions.	
In grades 6-8, students model complex and microscopic structures and systems and visualize how their function depends on the shapes, composition, and relationships among its parts. They analyze many complex natural and designed structures and systems to determine how they function. They design structures to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
In grades 9-12, students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. They infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.	HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

7. Stability and Change are the primary concerns of many, if not most scientific and engineering endeavors. **"**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. . . . 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.

"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.

"In designing systems for stable operation, the mechanisms of external controls and internal 'feedback' loops are important design elements; feedback is 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.

"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." (p. 99-100)

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students observe some things stay the same while other things change, and things may change slowly or rapidly.	2-ESS2-1. Compare multiple solutions designed to slow or prevent wind or water from changing the shape of the land.
In grades 3-5, students measure change in terms of differences over time, and observe that change may occur at different rates. Students learn some systems appear stable, but over long periods of time they will eventually change.	
In grades 6-8, students explain stability and change in natural or designed systems by examining changes over time, and considering forces at different scales, including the atomic scale. Students learn changes in one part of a system might cause large changes in another part, systems in dynamic equilibrium are stable due to a balance of feedback mechanisms, and stability might be disturbed by either sudden events or gradual changes that accumulate over time	MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
In grades 9-12, students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.	HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

How Are the Crosscutting Concepts Connected?

Although each of the seven crosscutting concepts can be used to help students recognize deep connections between seemingly disparate topics, it can sometimes be helpful to think of how they are connected to each other. The connections can be envisioned in many different ways. The following is one way to think about their interconnections.

Patterns

Patterns stand alone because patterns are a pervasive aspect of all fields of science and engineering. When first exploring a new phenomenon, children will notice similarities and differences leading to ideas for how they might be classified. The existence of patterns naturally suggests an underlying cause for the pattern. For example, observing snowflakes are all versions of six-side symmetrical shapes suggests something about how molecules pack together when water freezes; or, when repairing a device a technician would look for a certain pattern of failures suggesting an underlying cause. Patterns are also helpful when interpreting data, which may supply valuable evidence in support of an explanation or a particular solution to a problem.

Causality

Cause and effect lies at the heart of science. Often the objective of a scientific investigation is to find the cause that underlies a phenomenon, first identified by noticing a pattern. Later, the development of theories allows for predictions of new patterns, which then provides evidence in support of the theory. For example, Galileo's observation that a ball rolling down an incline gathers speed at a constant rate eventually led to Newton's Second Law of Motion, which in turn provided predictions about regular patterns of planetary motion, and a means to guide space probes to their destinations.

Structure and function can be thought of as a special case of cause and effect. Whether the structures in question are living tissue or molecules in the atmosphere, understanding their structure is essential to making causal inferences. Engineers make such inferences when examining structures in nature as inspirations for designs to meet people's needs.

Systems

Systems and system models are used by scientists and engineers to investigate natural and designed systems. The purpose of an investigation might be to explore how the system functions, or what may be going wrong. Sometimes investigations are too dangerous or expensive to try out without first experimenting with a model.

Scale, proportion, and quantity are essential considerations when deciding how to model a phenomenon. For example, when testing a scale model of a new airplane wing in a wind tunnel, it is essential to get the proportions right and measure accurately or the results will not be valid. When using a computer simulation of an ecosystem, it is important to use informed estimates of population sizes to make reasonably accurate predictions. Mathematics is essential in both science and engineering.

Energy and matter are basic to any systems model, whether of a natural or a designed system. Systems are described in terms of matter and energy. Often the focus of an investigation is to determine how energy or matter flows through the system, or in the case of engineering to modify the system, so a given energy input results in a more useful energy output.

Stability and change are ways of describing how a system functions. Whether studying ecosystems or engineered systems, the question is often to determine how the system is changing over time, and which factors are causing the system to become unstable.

Conclusion

The purpose of this appendix is to explain the rationale behind integrating crosscutting concepts into the K-12 science curriculum and to illustrate how the seven crosscutting concepts from the *Framework* are integrated into the performance expectations within the NGSS. The crosscutting concepts' utility will be realized when curriculum developers and teachers develop lessons, units, and courses using the crosscutting concepts to tie together the broad diversity of science and engineering core ideas in the curriculum to realize the clear and coherent vision of the *Framework*.

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Performance Expectations Coded to Crosscutting Concepts

	Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Patterns	*K-LS1-1, K-ESS2-1, 1-LS1-2, 1-LS3-1, 1-ESS1-1, 1-ESS1-2, 2-PS1-1, 2-ESS2-2, 2-ESS2-3*	*3-PS2-2, 3-LS1-1, 3-LS3-1, 3-ESS2-1, 3-ESS2-2, 4-PS4-1, 4-PS4-3, 4-ESS1-1, 4-ESS2-2, 5-ESS1-2*	*MS-PS1-2, MS-PS4-1, MS-LS2-2, MS-LS4-1, MS-LS4-2, MS-LS4-3, MS-ESS1-1, MS-ESS2-3, MS-ESS3-2*	*HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS1-5, HS-PS2-4, HS-LS4-1, HS-LS4-3, HS-ESS1-5*
Cause and Effect	*K-PS2-1, K-PS2-2, K-PS3-1, K-PS3-2, K-ESS3-2, K-ESS3-3, 1-PS4-1, 1-PS4-2, 1-PS4-3, 2-PS1-1, 2-LS2-1*	*3-PS2-1, 3-PS2-3, 3-LS2-1, 3-LS3-2, 3-LS4-2, 3-LS4-3, 3-ESS3-1, 4-PS4-2, 4-ESS2-1, 4-ESS3-1, 4-ESS3-2, 5-PS1-4, 5-PS2-1*	*MS-PS1-4, MS-PS2-3, MS-PS2-5, MS-LS1-4, MS-LS1-5, MS-LS2-1, MS-LS3-2, LS4-4, MS-LS4-5, MS-LS4-6, MS-ESS2-5, MS-ESS3-1, MS-ESS3-3, MS-ESS3-4*	*HS-PS2-4, HS-PS3-5, HS-PS4-1, HS-PS4-4, HS-PS4-5, HS-LS2-8, HS-LS3-1, HS-LS3-2, HS-LS4-2, HS-LS4-4, HS-LS4-5, HS-LS4-6, HS-ESS2-4, HS-ESS3-1*
Scale, Proportion, and Quantity		*3-LS4-1, 5-PS1-1, 5-PS2-2, 5-PS1-3, 5-ESS1-1, 5-ESS2-2*	*MS-PS1-1, MS-PS3-1, MS-PS3-4, MS-LS1-1, MS-ESS1-3, MS-ESS1-4, MS-ESS2-2*	*HS-LS2-1, HS-LS2-2, HS-LS3-3, HS-ESS1-1, HS-ESS1-4*
Systems and System Models	*K-ESS3-1, K-ESS2-2*	*3-LS4-4, 4-LS1-1, 5-LS2-1 5-ESS2-1, 5-ESS3-1*	*MS-PS2-1, MS-PS2-4, MS-PS3-2, MS-LS1-3, MS-ESS1-2, MS-ESS2-6*	*HS-PS2-2, HS-PS3-1, HS-PS3-4, HS-PS4-3, HS-LS1-2, HS-LS1-4, HS-LS2-5, HS-ESS3-6*
Energy and Matter	*2-PS1-3*	*4-PS3-1, 4-PS3-2, 4-PS3-3, 4-PS3-4, 5-PS3-1, 5-LS1-1*	*MS-PS1-5, MS-PS1-6, MS-PS3-3, MS-PS3-5, MS-LS1-6, MS-LS1-k, MS-LS1-7, MS-LS2-3, MS-ESS2-4*	*HS-PS1-4, HS-PS1-7, HS-PS1-8, HS-PS3-2, HS-PS3-3, HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3, HS-ESS1-2, HS-ESS1-3, HS-ESS2-3, HS-ESS2-6*
Structure and Function	*1-LS1-1, 2-LS2-2, K-2-ETS1-2*		*MS-PS1-5, MS-PS1-6, MS-PS4-a, MS-PS4-2, MS-PS4-3, MS-LS1-6, MS-LS1-7, MS-LS3-1*	*HS-PS2-6, HS-LS1-1, HS-ESS2-5*
Stability and Change	*2-ESS1-1, 2-ESS2-1*		*MS-PS2-2, MS-LS2-4, MS-LS2-5, MS-ESS2-1, MS-ESS3-5*	*HS-PS1-6, HS-PS4-2, HS-LS1-3, HS-LS2-6, HS-LS2-7, HS-ESS1-6, HS-ESS2-1, HS-ESS2-2, HS-ESS2-7, HS-ESS3-3, HS-ESS3-4, HS-ESS3-5*