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.

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.

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;

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> ■ 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