DRAFT: NAEP CONTENT AND BOUNDARY STATEMENTS

Introduction and Questions

This document contains the NAEP Framework introductory essays, content statements, and DRAFT boundary statements. Content boundaries fall under five general categories:

1. Examples, phenomena, or observations: There may be limits to the phenomena, examples, or observations that will be used in assessment items. For example, students may or may not be asked to apply laws of motion to electrons, or answer questions about a detritus-based food chain.
2. Instruments, units of measurement, and categories for classification: In some cases, boundaries will describe the level of precision expected of students in measuring or classifying phenomena, or in interpreting measurements.
3. Representations: Students will be expected to use different types of representations (charts, graphs, diagrams, formulas, etc.) at different grades and for different subtopics. Also, boundaries will attend to the kinds of mathematical operations or equations and chemical formulas that will appear on assessment items.
4. Technical vocabulary: There may be technical terms beyond those that appear in the content statements that could be included in assessment items; conversely, some terms may be considered off-limits.
5. Clarification/Other: This is an opportunity to comment on the boundaries, for example, further specifying the content encompassed by the more general content statements and boundaries or the suitable types of representation.

The boundary statements are currently being revised, so your comments would be helpful. In providing your feedback on the content boundary tables and chains, please focus on the following three questions:

1. Are the boundary statements consistent with the content statements? If no, please suggest revisions to the boundary statements.
2. Are the boundary statements appropriate to the grade level? If no, please suggest revisions to the boundary statements.

I would also be interested in your thoughts on a couple of other questions. There are sometimes inconsistencies in the form and level of details among the boundary statements, and I am supposed to help do a revision that resolves those inconsistencies. So could you think about two other questions:

1. What inconsistences among the boundaries for different topics need to be resolved?
2. What about the boundaries is most important for the audiences of the Michigan Content Expectations: assessment developers, curriculum developers, teachers, and administrators?

Physical Science

Physical science principles, including fundamental ideas about matter, energy, and motion, are powerful conceptual tools for making sense of phenomena in physical, living, and Earth systems. Familiar changes—an ice cube melting, a baseball changing direction after being struck by a bat, the appearance of a bolt of lightning, the formation and erosion of mountains, and the growth of a plant—can be explained using these fundamental ideas.[1]

Energy is the constant in an ever-changing world. Energy from the sun fuels electrical storms, hurricanes, tornados, and photosynthesis. In turn, the products of photosynthesis (carbohydrates and oxygen) react during respiration to fuel the life processes, such as growth and reproduction, of plants and animals. Consequently, it is important for students to develop an understanding of physical science principles early and to appreciate their usefulness across Physical Science, Life Science, and Earth and Space Science.

The physical science principles to be assessed are written as content statements and sorted into three topics—Matter, Energy, and Motion. Matter is the "stuff" of the natural world. Energy is involved in all changes in matter. Motion of the heavenly bodies, of objects found in daily experiences (e.g., balls, birds, cars), and of the tiny particles (atoms, molecules, and their component parts) composing all objects and substances is the result of interactions of matter and energy. The content statements have been divided into topics and subtopics as summarized in Table 5.

Table 5. Physical Science Content Topics and Subtopics

Matter
Properties of Matter Changes in Matter
Energy
Forms of Energy Energy Transfer and Conservation
Motion
Motion at the Macroscopic and Molecular Levels Forces Affecting Motion

[1] The importance of developing understanding early and making connections among the physical, life, Earth, and space sciences has motivated increased attention on physical science in elementary school and prompted consideration of rearranging the usual Earth–life–chemistry–physics curriculum sequence.

Matter

The topic, Matter, is divided into two subtopics: Properties of Matter and Changes in Matter. Conservation of mass, the particulate model of matter, and the Periodic Table of the Elements are the conceptual glue tying together these two subtopics and their related principles.

Properties of Matter

Matter has physical and chemical properties. Physical properties common to all matter as well as those physical properties unique to solids, liquids, and gases are included in the *Framework*, as are chemical properties. All objects and substances in the natural world are composed of matter. Matter has two fundamental properties: matter takes up space, and matter has inertia—it changes motion only when under the influence of a net force (grade 4). See the following textbox, "A Matter of Mass," for more on mass vs. weight and the *Framework's* treatment of this distinction.

Clarification: A Matter of Mass

Mass is a property common to all objects. It is the amount of matter (or "stuff") in an object. The more mass an object has, the more inertia (or "sluggishness") it displays when attempts are made to change its speed or direction. Mass is measured in grams (g) or kilograms (kg) (1 kg=1000 g) using a beam or electronic balance. [2]

Weight, on the other hand, is a measure of the force of attraction (gravitational force) between an object and Earth. Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. Force and weight are measured in newtons (N) using a spring scale.

Changing an object's position (say from Earth to the moon) will change its weight, but not its mass. For example, on the surface of Earth, a cannon ball has a mass of 10 kg and a weight of 98 N. On the surface of the moon, that same cannon ball still has a mass of 10 kg, but its weight is only 16 N. So, the cannon ball weighs less on the moon than on Earth, even though nothing has been taken away. Why? Because of the moon's lesser mass, the force of attraction between the moon and the cannon ball is less than the force of attraction between Earth and the cannon ball. Hence, it is said that an object on the moon weighs less than the same object weighs on Earth.

These concepts of mass and weight are complicated and potentially confusing to 4th grade students. Hence, the *Framework* and *Specifications* use the more familiar term "weight" in grade 4 to stand for both weight and mass; this usage is denoted as follows: "weight (mass)." By grades 8 and 12, students are expected to understand the distinction between mass and weight, and thus, both terms will be used as appropriate.

[2] As found in current NAEP practice, metric units of measure are used for grades 4, 8, and 12.

Matter exists in several different physical states, each of which has unique properties (grade 4). Three of the most commonly encountered are solids, liquids, and gases. Shape and compressibility are examples of properties that distinguish solids, liquids, and gases (grade 4).

The particulate model of matter can be used to explain and predict the properties of states of matter, for example, why ice is harder than liquid water; and why ice (once formed) has a shape independent of its container while liquid water takes the shape of whatever container it is in (grade 4). In the particulate model of matter, the molecules or atoms of which matter is composed are assumed to be tiny particles in motion (grade 8). The motion is translational, rotational, and vibrational (grade 12). This model now can be used to explain the properties of solids, liquids, and gases, as well as changes of state. The particulate model can be used to explain the unique properties of water, as described in the following textbox.

Clarification: Unique Properties of Water

Grade 12: Matter—Changes in Matter
P12.5: Changes of state require a transfer of energy. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.

The unique properties of water have important consequences for Earth Systems and Life Science, including the origin and existence of life on Earth. Understanding the substance of water requires knowledge across the Physical Science categories of Matter, Energy, and Motion.

As with all kinds of matter, water's unique properties can be explained by the shape of its molecule, the forces between its molecules in solid (ice) and liquid states, and the resulting arrangement of molecules in solid and liquid states. In particular, in the solid state, the molecular bonds are such that they separate the molecules more than in the liquid state, leading to ice being less dense than liquid water. The specific heat of a substance is the amount of energy required to change 1 kg of it by 1^0C. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.

The detailed structures of molecules and atoms that compose them serve as models that explain the forces of attraction between molecules. The structure of atoms, especially the outermost electrons, explains the chemical properties of the elements and the formation of the chemical bonds made and broken during chemical reactions (grade 12). The Periodic Table of the Elements (introduced at grade 8) is another way in which order can be made out of the complexity of the variety of types of matter. (In grade 8, the emphasis is on observed periodicity of properties.) The Periodic Table demonstrates the relationship between the atomic number of the elements and their chemical and physical properties and provides a structure for inquiry into the characteristics of the chemical elements (grade 12).

Two classes of chemical substances serve as exemplars of chemical properties. One class is metals (elements) and the other class is acids (compounds). A chemical property of metals is to react with non-metals to form salts. Included among the properties of acids is the formation of characteristic colors when interacting with acid/base indicators and the interaction with bases to produce salts and water (neutralization) (grade 8).

Changes in Matter

Matter can undergo a variety of changes. Changes are physical if the relations between the molecules of the material are changed (e.g., changing from a solid to a liquid or from a liquid to a gas) (grade 4). When matter undergoes physical change, generally no changes occur in the structure of the molecules or atoms composing the matter (grade 8). Changes are chemical if they involve the rearrangement of how atoms are bound to one other, thereby changing the molecules of the material. These are changes in the structure of the outermost electron shell surrounding the nuclei of the interacting atoms (grade 12). Chemical changes either release energy to the surroundings or require energy to take place (grade 12). Changes are nuclear if the particles are removed from or added to the nucleus of the atom, changing the atoms themselves into different elements (grade 12).

That mass is conserved when matter undergoes physical and chemical changes is a powerful principle for understanding the natural world and was influential in the development of chemical theory. Adherence to the principle discourages the conclusion that something “disappears” (as water appears to disappear from a puddle) and encourages the search for the “missing” matter.

Nuclear reactions, involving changes in the nuclei of atoms, are generally very high-energy and result in the formation of atoms different from those that began the process. In nuclear reactions, an appreciable amount of mass is converted into energy (grade 12).

Energy[3]

The topic, energy, is divided into two subtopics, one addressing the forms of energy and the other energy transfer and conservation.

Forms of Energy

Knowing the characteristics of familiar forms of energy (grade 4) and the scientific categories of potential and kinetic energy (grade 8) are useful in coming to an understanding that, for the most part, the natural world can be explained and is

[3] There are different approaches to helping students understand the concept of energy and related observable phenomena, such as light, heat, and sound. These differences are reflected in this *Framework*'s reference documents and have therefore influenced the framing of the Physical Science, Life Science, and Earth and Space Science content statements.

predictable. The most basic characteristics of thermal[4], light, sound, electrical, and mechanical energy and the relationship between changes in the natural world and energy are included in the *Framework*. That two objects, one at a higher temperature than the other, come to the same temperature when placed in contact with each other is a familiar experience. Heat as a concept can be used to explain this experience (grade 8).

Energy Transfer and Conservation

That energy is conserved can be demonstrated by keeping track of the familiar forms of energy as they are transferred from one object to another. The chemical potential energy in a battery is transferred by electric current to a light bulb, which in turn transfers the energy in the form of heat (thermal energy) and light to its surroundings (grade 4). The energy stored in the battery decreases as its surroundings are heated. The loss in chemical potential energy equals the light and heat (thermal energy) transferred by the bulb and the wires to their surroundings. Quantitative accounting is complex; however, on a qualitative basis, both the ability to trace energy transfer and the understanding that energy is conserved (grade 8) are of great explanatory and predictive value. The sun as the main energy source for the Earth provides opportunity at all grade levels to make important connections between the science disciplines (see following textbox).

Motion

The topic, motion, is divided into two subtopics. The first addresses motion at the macroscopic and molecular levels, and the second addresses the forces that affect motion.

Motion at the Macroscopic and Molecular Levels

Objects observed in daily life undergo different kinds of motion (grade 4). The *Framework* distinguishes three kinds of motion (translational, rotational, vibrational) with emphasis on the translational motion of objects in the natural environment. Translational motion is more difficult to describe than it appears because descriptions depend on the position of the observer and the frame of reference used. Speed (grades 4 and 8), velocity (grade 12), and acceleration (grade 12) of objects in translational motion are described in terms of change in direction and position in a time interval.

Forces Affecting Motion

Adding energy to a substance changes the motion of the molecules composing the substance. So, too, it takes energy to change the motion of macroscopic objects. The energy change is understood in terms of forces. It takes energy for a baseball pitcher to set the ball in motion toward the batter. Pushes and pulls applied to objects often result in changes in motion (grade 4). Principles germane to the relationship of forces and motion serve to motivate the search for forces when objects change their motion or when an object remains at rest when it seems that the forces acting on it should result in setting it

[4] The term "heat" in Physical Science is used in grade 4 to stand for thermal energy; this usage is denoted as follows: "heat (thermal energy)." "Thermal energy" is used in grades 8 and 12.

in motion (grade 8).

Some forces act through physical contact of objects while others act at a distance. The force of a bat on a ball and the downward push of a lead block on a tabletop are contact forces. Gravitational and magnetic forces act at a distance (grade 8). Magnets do not need to be in contact to attract or repel each other. The Earth and an airplane do not need to be in contact for a force of attraction to exist between them. Qualitative relationships (grade 8) and quantitative relationships (grade 12) between the mass of an object, the magnitude and direction of the net force on the object, and its acceleration are powerful ideas to explain and predict changes in the natural world.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Matter		
Properties of Matter: From physical properties common to all objects and substances and physical properties common to solids, liquids and gases (4) to chemical properties, particulate nature of matter, and the Periodic Table of Elements (8) to characteristics of sub-atomic particles and atomic structure (12).		
P4.1: Objects and substances have properties. Weight (mass) and volume are properties that can be measured using appropriate tools.[5] **P4.2:** Objects vary in the extent to which they absorb and reflect light and conduct heat (thermal energy) and electricity. **P4.3:** Matter exists in several different states; the most commonly encountered are solid, liquid, and gas. Each state of matter has unique properties. For instance, solids and liquids are not easily compressed; the shape of a solid is independent of its container; liquids and gases take the shape of their containers. **P4.4:** Some objects are composed of a single substance; others are composed of more than one substance. **P4.5:** Magnets can repel or attract other magnets. They can also attract certain non-magnetic objects at a distance.	**P8.1:** Properties of solids, liquids, and gases are explained by a model of matter that is composed of tiny particles in motion. **P8.2:** Chemical properties of substances are explained by the structure of atoms and molecules. **P8.3**: All substances are composed of one or more of approximately one hundred elements. The Periodic Table organizes the elements into families of elements with similar properties. **P8.4:** Elements are a class of substances composed of a single kind of atom. Compounds are composed of two or more different elements. Each element and compound has physical and chemical properties, such as boiling point, density, color, and conductivity, which are independent of the amount of the sample.[6] **P8.5:** Substances are classified according to their physical and chemical properties. Metals and acids are examples of such classes. Metals are a class of elements that exhibit common physical properties such as conductivity and common chemical properties such as interacting with non-metals to produce salts. Acids are a class of compounds that exhibit common chemical properties including a sour taste, characteristic color changes with litmus and other acid/base indicators, and the tendency to react with bases to produce a salt and water.	**P12.1:** Differences in the physical properties of solids, liquids, and gases are explained by the ways in which the molecules of the substances are arranged and the strength of the forces of attraction between the molecules. **P12.2:** Electrons, protons, and neutrons are parts of the atom and have measurable properties including mass and, in the case of protons and electrons, charge. The nuclei of atoms are composed of protons and neutrons. A kind of force that is only visible at nuclear distances holds the particles of the nucleus together against the electrical repulsion between the protons. **P12.3:** In the Periodic Table, elements are arranged according to the number of protons (called the atomic number). This organization illustrates commonality and patterns of physical and chemical properties among the elements. **P12.4:** In a neutral atom, the positively charged nucleus is surrounded by the same number of negatively charged electrons. Atoms of an element whose nuclei have different numbers of neutrons are called isotopes.

[5] See textbox on p. 27 for more detail on the distinction between weight and mass.
[6] While this content statement generally holds, there are some compounds that decompose before boiling.

Grade 4	Grade 8	Grade 12
Matter		
Changes in Matter: From changes of state (4) to physical and chemical changes and conservation of mass (8) to particulate nature of matter, unique physical characteristics of water, and changes at the atomic and molecular level during chemical changes (12).		
P4.6: One way to change matter from one state to another and back again is by heating and cooling.	**P8.6:** Changes of state are explained by a model of matter composed of tiny particles that are in motion. When substances undergo changes of state, neither atoms nor molecules themselves are changed in structure. Mass is conserved when substances undergo changes of state. **P8.7:** Chemical changes can occur when two substances, elements, or compounds interact and produce one or more different substances, whose physical and chemical properties are different from the interacting substances. When substances undergo chemical change, the number of atoms in the reactants is the same as the number of atoms in the products. Mass is conserved when substances undergo chemical change. The mass of the interacting substances (reactants) is the same as the mass of the substances produced (products).	**P12.5:** Changes of state require a transfer of energy. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.[7] **P12.6:** An atom's electron configuration, particularly of the outermost electrons, determines how the atom can interact with other atoms. The interactions between atoms that hold them together in molecules are called chemical bonds. **P12.7:** A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other chemical reactions, atoms interact with one another by sharing electrons to create a bond. An important example is carbon atoms, which can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

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[7] See textbox on p. 28 for more detail on the unique properties of water.

Grade 4	Grade 8	Grade 12
Energy		
Forms of Energy: From examples of forms of energy (4) to kinetic energy, potential energy, and light energy from the sun (8) to nuclear energy and waves (12).		
P4.7: Heat (thermal energy), electricity, light, and sound are forms of energy.[8] **P4.8:** Heat (thermal energy) results when substances burn, when certain kinds of materials rub against each other, and when electricity flows though wires. Metals are good conductors of heat (thermal energy) and electricity. Increasing the temperature of any substance requires the addition of energy. **P4.9:** Light travels in straight lines. When light strikes substances and objects through which it cannot pass, shadows result. When light travels obliquely from one substance to another (air and water), it changes direction. **P4.10:** Vibrating objects produce sound. The pitch of sound can be varied by changing the rate of vibration.	**P8.8:** Objects and substances in motion have kinetic energy. For example, a moving baseball can break a window; water flowing down a stream moves pebbles and floating objects along with it. **P8.9:** Three forms of potential energy are gravitational, elastic, and chemical. Gravitational potential energy changes in a system as the relative positions of objects are changed. Objects can have elastic potential energy due to their compression, or chemical potential energy due to the arrangement of the atoms. **P8.10:** Energy is transferred from place to place. Light energy from the sun travels through empty space to Earth (radiation). Thermal energy travels from a flame through the metal of a cooking pan to the water in the pan (conduction). Air warmed by a fireplace moves around a room (convection). Waves, including sound and seismic waves, waves on water, and light waves, have energy and transfer energy when they interact with matter. **P8.11:** A tiny fraction of the light energy from the sun reaches Earth. Light energy from the sun is Earth's primary source of energy, heating Earth surfaces and providing the energy that results in wind, ocean currents, and storms.	**P12.8:** Molecules that compose matter are in constant motion (translational, rotational, and vibrational). **P12.9:** Energy may be transferred from one object to another during collisions. **P12.10:** Electromagnetic waves are produced by changing the motion of charges or by changing magnetic fields. The energy of electromagnetic waves is transferred to matter in packets. The energy content of the packets is directly proportional to the frequency of the electromagnetic waves. **P12.11:** Fission and fusion are reactions involving changes in the nuclei of atoms. Fission is the splitting of a large nucleus into smaller nuclei and particles. Fusion involves joining of two nuclei at extremely high temperature and pressure. Fusion is the process responsible for the energy of the sun and other stars.

[8] See footnote on p. 30 for more detail on the *Framework*'s use of the terms "heat" and "thermal energy."

Grade 4	Grade 8	Grade 12
Energy		
Energy Transfer and Conservation: From electrical circuits (4) to energy transfer and conservation of energy (8) to translational, rotational, and vibrational energy of atoms and molecules, and chemical and nuclear reactions (12).		
P4.11: Electricity flowing through an electrical circuit produces magnetic effects in the wires. In an electrical circuit containing a battery, a bulb, and a bell, energy from the battery is transferred to the bulb and the bell, which in turn transfer the energy to their surroundings as light, sound, and heat (thermal energy).	**P8.12:** As an object falls, its potential energy decreases as its speed, and consequently, its kinetic energy increases. While falling, some of an object's kinetic energy is transferred to the medium through which it falls, setting the medium into motion and heating it. When energy is transferred from one system to another, the quantity of energy before transfer equals the quantity of energy after transfer. **P8.13:** Nuclear reactions take place in the sun. In plants, light from the sun is transferred to oxygen and carbon compounds, which, in combination, have chemical potential energy (photosynthesis).	**P12.12:** Heating increases the translational, rotational, and vibrational energy of the atoms composing elements and the molecules or ions composing compounds. As the translational energy of the atoms, molecules, or ions increases, the temperature of the matter increases. Heating a sample of a crystalline solid increases the vibrational energy of the atoms, molecules, or ions. When the vibrational energy becomes great enough, the crystalline structure breaks down and the solid melts. **P12.13:** The potential energy of an object on Earth's surface is increased when the object's position is changed from one closer to Earth's surface to one further from Earth's surface. **P12.14:** Chemical interactions either release energy to the environment (exothermic) or absorb energy from the environment (endothermic). **P12.15:** Nuclear reactions—fission and fusion—convert matter into appreciable amounts of energy. **P12.16:** Total energy is conserved in a closed system.

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Grade 4	Grade 8	Grade 12
Motion		
Motion at the Macroscopic and Molecular Levels: From qualitative descriptions of position and motion (4) to speed as a quantitative description of motion and graphical representations of speed (8) to velocity and acceleration as quantitative descriptions of motion and the representation of linear velocity and acceleration in tables and graphs (12).		
P4.12: An object's position can be described by locating the object relative to other objects or a background. The description of an object's motion from one observer's view may be different from that reported from a different observer's view. **P4.13:** An object is in motion when its position is changing. The speed of an object is defined by how far it travels divided by the amount of time it took to travel that far.	**P8.14:** An object's motion can be described by its speed and the direction in which it is moving. An object's position can be measured and graphed as a function of time. An object's speed can be measured and graphed as a function of time.	**P12.17:** The motion of an object can be described by its position and velocity as functions of time, and by its average speed and average acceleration during intervals of time.

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Grade 4	Grade 8	Grade 12
Motion		
Forces Affecting Motion: From the association of changes in motion with forces and the association of objects falling toward Earth with gravitational force (4) to qualitative descriptions of magnitude and direction as characteristics of forces, addition of forces, contact forces, forces that act at a distance, and net force on an object and its relationship to the object's motion (8) to quantitative descriptions of universal gravitational and electric forces, and relationships among force, mass, and acceleration (12).		
P4.14: The motion of objects can be changed by pushing or pulling. The size of the change is related to the size of the force (push or pull) and the weight (mass) of the object on which the force is exerted. When an object does not move in response to a push or a pull, it is because another push or pull (friction) is being applied by the environment. **P4.15:** Earth pulls down on all objects with a force called gravity. With a few exceptions (helium filled balloons), objects fall to the ground no matter where on Earth the object is.	**P8.15:** Some forces between objects act when the objects are in direct contact or when they are not touching. Magnetic, electrical, and gravitational forces can act at a distance. **P8.16:** Forces have magnitude and direction. Forces can be added. The net force on an object is the sum of all the forces acting on the object. A non-zero net force on an object changes the object's motion; that is, the object's speed and/or direction of motion changes. A net force of zero on an object does not change the object's motion; that is, the object remains at rest or continues to move at a constant speed in a straight line.	**P12.18:** The motion of an object changes only when a net force is applied. **P12.19:** The magnitude of acceleration of an object depends directly on the strength of the net force and inversely on the mass of the object. This relationship ($a=F_{net}/m$) is independent of the nature of the force. **P12.20:** Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted by the second object back on the first object. In closed systems, momentum is the quantity of motion that is conserved. Conservation of momentum can be used to help validate the relationship $a=F_{net}/m$. **P12.21:** Gravitation is a universal attractive force that each mass exerts on any other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them. **P12.22:** Electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the electric force is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them. Between any two charged particles, the electric force is vastly greater than the gravitational force.

Table 7. Physical Science Content Boundaries for Grades 4, 8, and 12

	Grade 4	Grade 8	Grade 12
Properties of Matter (PM)			
Examples	**P4.PM1:** Common objects, solid and liquid materials found in children's daily lives. Exclusions: **P4.PM2:** In general, avoid unusual materials and mixtures such as mud that cannot be clearly classified as solid or liquid.	**P8.PM1:** Common objects, solid and liquid materials found in children's daily lives. **P8.PM2:** Some common gases: oxygen, carbon dioxide, air, water vapor, common smells, and volatile liquids	**P12.PM1:** Elements and compounds listed above **P12.PM2:** Mixtures of those elements and compounds, including solutions
Measurement/Instruments	**P4.PM3:** Qualitative descriptions using common properties: solid and liquid, color names, stretchy, springy, etc. **P4.PM4:** Quantitative linear measures, using rulers or meter sticks, in cm and m. **P4.PM5:** Volume measures using repeated cubes or measuring cups, in mL or L. **P4.PM6:** Weight (mass) measures or qualitative comparisons using spring scales or double pan balances in g or kg. Exclusions: **P4.PM7:** Volume measures using cm3 **P4.PM8:** Newtons (especially since we say that the weight/mass distinction is inappropriate at this level)	**P8.PM3:** Qualitative descriptions of properties solids, liquids, and gases **P8.PM4:** Quantitative measures of mass, volume, and linear measures, accurate to tenths of g, mL, cm., using standard measuring instruments, including triple beam balances **P8.PM5:** Calculated measures of density in g/mL	**P12.PM3:** Quantitative measures of linear dimensions, mass, volume, density, melting point, boiling point using standard laboratory instruments **P12.PM4:** Classification of elements as metals or non-metals **P12.PM5:** Qualitative descriptions of other chemical and physical properties: limited to conductivity of heat and electricity, solubility Exclusions: **P12.PM6:** Classification of materials as pure substances or mixtures
Representations	**P4.PM9:** Simple bar graphs and tables, pictures or diagrams.	**P8.PM6:** Drawings of atoms and molecules showing how atoms are linked to make molecules (not internal structure of atoms). **P8.PM7:** Graphs and tables Exclusions: **P8.PM8:** Chemical formulas and equations	**P12.PM7:** Chemical formulas and equations involving elements and compounds listed above **P12.PM8:** Drawings of atoms and molecules **P12.PM9:** Graphs and tables

	Grade 4	Grade 8	Grade 12
Properties of Matter (PM)			
Technical Vocabulary	**P4.PM10:** Generally limited to vocabulary in content statements.	**P8.PM9:** Generally limited to vocabulary in content statements.	**P12.PM10:** Generally limited to vocabulary in content statements, with the addition of Elements on the first two rows of the Periodic Table (Nos. 1-18) **P12.PM11:** Other common elements: iron, gold, silver, mercury, iodine, potassium **P12.PM12:** Common compounds of those elements
Clarification			

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	Grade 4	Grade 8	Grade 12
Changes in Matter (CM)			
Examples	**P4.CM1:** Changes of state at the macroscopic level: melting, freezing, evaporation, condensation **P4.CM2:** Other physical changes at the macroscopic level: thermal expansion, solution, diffusion **P4.CM3:** Familiar Chemical Changes: cooking, formation of carbon dioxide from baking powder baking soda, yeast **P4.CM4:** Temperature changes associated with physical and chemical changes **P4.CM5:** Familiar relationships between changes in matter and heating and cooling	**P8.CM1:** Use of the particulate nature of matter to explain physical changes (changes of state including sublimation, diffusion, thermal expansion, solution) at the molecular/atomic level **P8.CM2:** Chemical changes that illustrate evidence that a change is chemical rather than physical. **P8.CM3:** Differences between physical and chemical changes (physical Changes are reversible; chemical changes involve changes in color, etc.) **P8.CM4:** Qualitative measures of temperature change and thermal energy associated with chemical and physical changes **P8.CM5:** Distinction between chemical/physical changes that result in taking energy from the surroundings and those that add energy to the surroundings.	**P12.CM1:** Classification of chemical changes as oxidation, acid-base (neutralization), synthesis. **P12.CM2:** Photosynthesis included as a synthesis reaction. **P12.CM3:** Respiration included as an oxidation reaction **P12.CM4:** Use of particulate nature of matter to explain chemical changes **P12.CM5:** Use of particulate nature of matter to explain the difference between physical and chemical changes **P12.CM6:** Quantitative measures of temperature and thermal energy changes associated with physical and chemical changes
Instruments	**P4.CM6:** Beakers, graduated cylinders, balances, thermometers **P4.CM7:** Metric units of weight (mass), volume, and temperature	**P8.CM6:** Calorie as a measure of thermal energy and stored chemical energy	

	Grade 4	Grade 8	Grade 12
Changes in Matter (CM)			
Representations	**P4.CM8:** Chemical symbols for common substances such as water and carbon dioxide **P4.CM9:** Diagrams representing particles in solids, liquids, and gases **P4.CM10:** Bar graphs	**P8.CM7:** Structural diagrams **P8.CM8:** Chemical formulas for familiar chemical reactions **P8.CM9:** Diagrams representing particles and forces among them in solids, liquids and gases **P8.CM10:** Diagrams representing the atomic structure of simple molecules such as water **P8.CM11:** Interpretation of chemical symbols and formulas **P8.CM12:** Line graph	**P12.CM7:** Symbols and structural diagrams for elements and compounds of importance in Life and Earth and Space Sciences such as sugars and earth materials (minerals) **P12.CM8:** Chemical equations for oxidation, neutralization, and synthesis reactions of importance in Life and Earth and Space Sciences. **P12.CM9:** Diagrams illustrating the structures of atoms, the outer electrons and the nuclei **P12.CM10:** Simple calculations relating temperature change and thermal energy measured in calories
Technical Vocabulary	**P4.CM11:** See principles outlined in introductory statement on boundaries for Physical Science		
Clarification			

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	Grade 4	Grade 8	Grade 12
Energy Transfer and Conservation (ET)			
Examples	**P4.ET1:** Energy transfer in familiar contexts (systems) **P4.ET2:** Electrical circuits: transfer of chemical to electrical to heat, light, sound, motion (in wires, light bulbs, buzzers, bells, fans); qualitative relationships between batteries and light bulbs. **P4.ET3:** Burning organic substances (wood, wax, sugar, nuts): transfer of chemical energy to heat, light and sound (connection to P4.8); qualitative relationships between amount of fuel and heat/light produced **P4.ET4:** Human body: transfer of chemical energy (food) to heat and motion (connection to L4.2)	**P8.ET1:** Energy transfer in familiar contexts (systems) **P8.ET2:** Falling objects: transfer of gravitational potential energy to kinetic energy and heat produced by friction. **P8.ET3:** Transfer of energy from a person lifting an object to gravitational potential energy. **P8.ET4:** Power plants: transfer of gravitational potential energy (water power) to mechanical energy to electrical energy; transfer of chemical energy from burning coal or natural gas to mechanical and to electrical energy **P8.ET5:** Plants: transfer of light energy to chemical energy **P8.ET6:** Qualitative relationships between the mass of combustible materials and the quantity of heat energy produced. (For example, when candles are used to heat water, the wax "disappears," and the temperature of the water increases. The mass of wax that burns is directly related to the increase in the temperature of the water.)	**P12.ET1:** Phenomena that are used to support a theory of matter composed of small particles in motion including those from "Properties of Matter" and "Changes in Matter," as well as sublimation, Brownian motion, and diffusions of a soluble solid in a liquid. **P12.ET2:** Calculations of the temperature of a mixture of two liquids of different temperatures and volumes **P12.ET3:** Qualitative analysis of the transfer of potential to kinetic energy as a body falls; transfer of kinetic energy to heat.
Instruments	**P4.ET5:** Comparison of calorie content of familiar foods	**P8.ET7:** Comparison of calorie expenditures of various physical activities	**P12.ET4:** Definition of a calorie

	Grade 4	Grade 8	Grade 12
Energy Transfer and Conservation (ET)			
Representations		**P8.ET8:** Diagrams illustrating translational, rotational, and vibrational motion of objects **P8.ET9:** Use of arrows to represent forces among molecules	**P12.ET5:** Graphical representation of changes of state as water is heated at a constant rate **P12.ET6:** Use of energy transfer and conservation to explain graphical representations of phase change as heat is added to a system at a constant rate **P12.ET7:** Mathematical reasoning and representations: Calorimetry: Calculation of changes in temperatures of objects in closed systems Qualitative comparisons of changes in potential energy with corresponding changes in kinetic energy. Calculations of gravitational potential energy of an object and the change in gravitational potential when the distance of the object from earth's surface is increased. Calculations of an object's kinetic energy and speed as the object's gravitational potential energy decreases.
Technical Vocabulary			
Clarification	**P4.ET6:** As one form of energy "disappears" from a system, other forms of energy "appear." **P4.ET7:** Note connections between this subtopic and content statement L4.2	**P8.ET10:** As the quantity of one form of energy in a system decreases the quantity of other forms of energy increases	**P12.ET8:** Kinetic molecular theory of matter is based on observations and phenomena of the type listed above and measurements noted below.[9]

[9] This is a specific instance of a set of boundaries that illustrates a big idea.

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	Grade 4	Grade 8	Grade 12
Motion at the Macroscopic and Molecular Levels (MM)			
Examples	**P4.MM1:** Qualitative comparisons of speed by comparing distances traveled in equal times or times to travel equal distances. **P4.MM2:** Position relative to reference object	**P8.MM1:** Qualitative comparisons of speeds in different parts of a journey. **P8.MM2:** Descriptions of the motion of one object relative to another where both are moving along a straight line. **P8.MM3:** Change in speed or direction for particular intervals of time	**P12.MM1:** Qualitative comparisons of average speeds and average accelerations in different parts of a journey and/or for different objects. **P12.MM2:** Use of vectors to describe the velocity of an object moving at several points along a curvilinear motion. **P12.MM3:** Interpretation and description of the motion of the object, given velocity vectors along a curvilinear path **P12.MM4:** Curvilinear paths can be circular or parabolic or elliptical or simply "around a corner." <u>Exclusions:</u> **P12.MM5:** Independence of horizontal and vertical motion for projectiles.
Instruments	**P4.MM3:** Clocks **P4.MM4:** Time (at an instant) as read on a clock **P4.MM5:** Time (interval) as found by subtracting the first clock reading from the final clock reading **P4.MM6:** Position and distance scales **P4.MM7:** Measuring distance with a ruler	**P8.MM4:** Reading speedometers	

	Grade 4	Grade 8	Grade 12
Motion at the Macroscopic and Molecular Levels (MM)			
Representations	**P4.MM8:** Pictures of positions of objects at different times relative to reference objects or distance scales	**P8.MM5:** Tables and graphs of position vs. time (clockreadings) and of speed vs. time (clockreadings)	**P12.MM6:** Tables and graphs of position vs. time and of speed vs. time (same big ideas as at 8th grade but with more complex motions such as speeds that change moment by moment or several different intervals of different constant speeds) **P12.MM7:** Pictures of projectiles **P12.MM8:** Calculations of average speeds and average accelerations for different parts of a journey.
Technical Vocabulary	**P4.MM9:** Reference object **P4.MM10:** Time **P4.MM11:** Distance (from one position on a reference scale to another) **P4.MM12:** Speed as "fastness"	**P8.MM6:** Average speed	**P12.MM9:** Instantaneous speed as "an average speed determined for a very short time interval" **P12.MM10:** Average velocity as "a vector including magnitude and direction" **P12.MM11:** Average acceleration
Clarification			

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	Grade 4	Grade 8	Grade 12
Forces Affecting Motion (FM)			
Examples	**P4.FM1:** Toys move across horizontal surfaces, and if no force keeps them going, they slow down at rates that depend on the kind of surface. **P4.FM2:** Dropped objects falling to the ground. **P4.FM3:** Heavier objects stretch or compress a spring-like object more than a lighter object does. **P4.FM4:** Passive as well as active forces, e.g., support force by a table holding an object up.	**P8.FM1:** Low friction surfaces such as air hockey pucks on air, block of ice on smooth table surface, low friction wheeled cart.	**P12.FM1:** Two different masses (different densities but equal volumes) fall from equal heights in approximately equal times. **P12.FM2:** Some objects fall more slowly than others when they have substantial air resistance (e.g. parachute) **P12.FM3:** Doing the same thing (e.g. rubbing or sticking) to each of two identical objects can create equal electrical charge on the two objects. **P12.FM4:** When two objects with the same kind of electrical charge are brought near each other, they move away from each other **P12.FM5:** When two objects with different kinds of electrical charge are brought near each other, they move toward each other **P12.FM6:** The closer two charged objects are, the greater the evidence of attraction or repulsion; when the charge is reduced on one or both objects, the attraction or repulsion is reduced. **P12.FM7:** Objects (e.g. pieces of paper, foil) might be caused to move away from a table or floor when an electrically charged object is brought above them.
Instruments	**P4.FM5:** Push or pull can be measured by the relative stretch or compression of an object (e.g. a spring or rubber ring) **P4.FM6:** Equal arm balances can be used to compare masses.	**P8.FM2:** Spring scales can be used to pull objects across different surfaces.	

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	Grade 4	Grade 8	Grade 12
Forces Affecting Motion (FM)			
Representations		**P8.FM3:** Force diagrams with arrows to represent the relative magnitude and direction of forces acting on an object of interest.	**P12.FM8:** *Force diagrams on each of two interacting objects; force diagrams with relative magnitudes can be used to compare the forces acting on each object of the pair **P12.FM9:** *Use of force diagrams and equations qualitatively to show how two different density objects can fall in approximately equal times, if air resistance is not a major factor, and explanations of how major air resistance on an object affects the force diagram and resulting motion of the object. **P12.FM10:** *a=Fnet/m to predict or compare the accelerations of objects, their masses, or the net force acting on them. **P12.FM11:** *Mv = mV to predict relative motions or relative masses of two interacting objects along a straight line, but not momentum in two directions. **P12.FM12:** *When the distance between two masses is doubled or tripled, the magnitude of the gravitational force is one quarter or one ninth. **P12.FM13:** *When the distance between two charges is doubled (or tripled), the magnitude of the electrical force is one quarter (or one ninth)
Technical Vocabulary	**P4.FM7:** Force as “a push or pull” **P4.FM8:** Weight (mass) as measures of heaviness. Inertial resistance to motion. **P4.FM9:** Friction as “a rubbing force”	**P8.FM4:** Net force **P8.FM5:** Magnitude and direction of force **P8.FM6:** Magnetic force, static electrical force, gravitational force	**P12.FM14:** Attract and repel **P12.FM15:** Momentum

	Grade 4	Grade 8	Grade 12
Forces Affecting Motion (FM)			
Clarification	**P4.FM10:** Include the relationships More force applied to one movable object will make it move (speed up) faster. With the same force applied to two objects the heavier one will move (speed up) more slowly. To get a heavier object and a lighter object to move (speed up) the same as each other, one will need to push/pull harder on the heavier object.	**P8.FM7:** Resolution of forces on an object should be confined to horizontal or vertical surfaces. **P8.FM8:** This subtopic includes a qualitative understanding of Newton's first two laws of motion applied to an object.	**P12.FM16:** Resolution of forces should be confined to horizontal, vertical, or inclines of 30 or 45 degrees. **P12.FM17:** Resolution of orthogonal forces should result in a vector at roughly 30, 60 or 45 degrees relative to one of the "first" vector. **P12.FM18:** This subtopic includes all three of Newton's Laws of Motion applied to two interacting objects. **P12.FM19:** In the above mathematical relationships/representations above (denoted with *), students having a qualitative or semi-quantitative understanding of the results is more important than calculating particular quantities

→ ACTION ITEM: Insert boundaries for Forms of Energy.

Life Science

Life science principles are essential for understanding the functioning of living organisms and their interactions with their environment. In addition, life science principles are crucial for understanding advances in science and technology and appreciating their implications for social and personal decisions. Take, for instance, the following discoveries of the past 25 years, all of which rely on understanding basic ideas in life science: the publication of the human genome and genomes of other organisms, the ability to monitor the oxygen level of specific regions of the brain, and the depletion of the ozone layer by human activities. The media regularly ask questions related to health and disease, such as what constitutes a healthy lifestyle and how to deal with the mutability of bacteria, viruses, and parasites that thwart efforts to develop antibiotics and vaccines. While science does not currently provide complete answers to questions like these, it provides the tools for understanding and addressing them.

Understanding principles in Life Science is inextricably linked with understanding principles in Physical Science and Earth and Space Science. “Living organisms are made of the same components as all other matter, involve the same kind of transformations of energy, and move using the same basic kinds of forces” (AAAS, 1989, p. 59).

Understanding living systems and their interactions with their environment requires not only understanding various levels of biological organization—molecules, cells, tissues/organs, organisms, populations, ecosystems—but also understanding interactions (including the transfer of information) within and across these levels and how they can change over time. For example, understanding how populations of organisms change over time is greatly facilitated by understanding the changes that occur in DNA molecules. These changes are manifest in an organism’s traits and may affect its ability to survive and reproduce, which can lead to changing proportions of traits in populations over time.

As summarized in Table 8, the Life Science content statements are sorted into topics and subtopics that, collectively, address structure, function, and patterns of change in living systems. However, any attempt to organize Life Science by a linear set of topics and subtopics, such as those listed below, is somewhat arbitrary. The overlap is evident in Table 9, Life Science Content Statements for Grades 4, 8, and 12.

Table 8. Life Science Content Topics and Subtopics

Structures and Functions of Living Systems
Organization and Development Matter and Energy Transformations Interdependence
Changes in Living Systems
Heredity and Reproduction Evolution and Diversity

Structures and Functions of Living Systems

This topic comprises the ways that living systems are organized and how living systems carry out their life functions. Reasoning about living systems often involves relating different levels of organization, from the molecule to the biosphere, and understanding how living systems are structured at each level. The functions of living systems at these levels, particularly how they transform matter and energy, are included, as are the interactions among living systems and how they depend on one another to carry out their functions.

Organization and Development

As was pointed out early in the 20th century, "Long ago it became evident that the key to every biological problem must finally be sought in the cell; for every living organism is, or at some time has been, a cell" (Wilson, 1928, p. 1). All living things are made up of cells, whose work is carried out by many different types of molecules. Cellular and molecular biology has the power to explain a wide variety of phenomena related to the organization and development of living systems, such as synthesis and reproduction, the extraction of energy from food, and regulation. Living organisms have a variety of observable features that enable them to obtain food and reproduce (grade 4). The functions of living organisms are carried out at different levels of organization. In multicellular organisms, cells form organs and organ systems (grade 8). Organisms are subsystems of populations, communities, ecosystems, and the biosphere. Cellular processes are carried out by molecules, particularly proteins. These processes are regulated, both internally and externally, by the environments in which cells exist, including local environments that lead to cell differentiation during the development of multicellular organisms (grade 12).

Matter and Energy Transformations

Matter and energy transformations are involved in all life processes, such as photosynthesis, growth and repair, cellular respiration, and the need of living systems for continual input of energy.

All single-celled and multicellular organisms have the same basic needs: water, air, a source of energy and materials for growth and repair, waste disposal, and conditions for growth and reproduction (grade 4). In terms of matter and energy transformations, the source of food is the distinguishing difference between plants and animals (see textbox below).

Clarification: "Food"

Both plants and animals require a source of energy and materials for growth and repair, and both plants and animals use high-energy compounds as a source of fuel and building material. Plants are distinguished from animals by the fact that plants have the capability (through photosynthesis) to take energy from light to form higher energy molecules containing carbon, hydrogen, and oxygen (carbohydrates) from lower energy molecules.

Plants are similar to animals in that, to make other molecules for their growth and reproduction, they use the energy that is released as carbohydrates react with oxygen. In making these other molecules, plants use breakdown products of carbohydrates, along with minerals from the soil and from fertilizers (known colloquially as "plant foods"), as building blocks. Plants also synthesize substances (carbohydrates, fats, proteins, vitamins) that are components of foods eaten by animals.

So, while synthesis and breakdown are common to both plants and animals, photosynthesis (the conversion of light energy into stored chemical energy) is unique to plants, making them the primary source of energy for all animals.

Basic needs are connected with the processes of growth and metabolism. Organisms are made up of carbon-containing molecules; these molecules originate in molecules that plants assemble from carbon dioxide and water. In converting carbon-containing molecules back to water and carbon dioxide, organisms release energy, making some of it available to support life functions (grade 8). Matter and energy transformations in cells, organisms, and ecosystems have a chemical basis (grade 12). The following textbox on the flow of energy through an ecosystem illustrates principles that cut across the content areas.

<u>Interdependence</u>

The species interaction in an ecosystem, the dynamics of population growth and decline, the use of resources by multiple species, their impact on their environment, and the complex interactions among all of these have enormous consequences to the survival of all species, including humans.

All animals and most plants depend on both other organisms and their environments for their basic needs (grade 4). Organisms interact with one another in a variety of ways,

such as producer/consumer, predator/prey, and parasite/host. In addition to competition among organisms, the size of populations depends on environmental conditions, such as the availability of water, light, and other suitable conditions (grade 8). Ecosystems are characterized by both stability and change, on which human populations can have an impact (grade 12).

Changes in Living Systems

This topic comprises how organisms reproduce, how they pass genetic information to their offspring, and how genetic information can change as it passes from one generation to the next. Over time, those changes can affect the size, diversity, and genetic composition of populations (i.e., the process of biological evolution).

Heredity and Reproduction

Organisms closely resemble their parents; their slight variations can accumulate over many generations and result in more obvious differences between organisms and their ancestors. Recent advances in biochemistry and cell biology have increased understanding of the mechanisms of inheritance and enabled the detection of disease-related genes. Such knowledge is making it possible to design and produce large quantities of substances to treat disease and, in years to come, may lead to cures.

All plants and animals (and one-celled organisms) develop and have the capacity to reproduce (grade 4). Reproduction, whether sexually or asexually, is a requirement for the survival of species. Characteristics of organisms are influenced by heredity and environment (grade 8). Genetic differences among individuals and species are fundamentally chemical. Different organisms are made up of somewhat different proteins. Reproduction involves passing the DNA with instructions for making these proteins from one generation to the next with occasional modifications (grade 12).

Evolution and Diversity

Earth's present-day life forms have evolved from common ancestors reaching back to the simplest one-celled organisms almost four billion years ago. Modern ideas about evolution provide a scientific explanation for three main sets of observable facts about life on Earth: the enormous number of different life forms that exist; the systematic similarities in anatomy and molecular chemistry seen within that diversity; and the sequences of changes in fossils found in successive layers of rock that have been formed over more than a billion years. The modern concept of evolution, including natural selection and common descent, provides a unifying principle for understanding the history of life on Earth, relationships among all living things, and the dependence of life on the physical environment. The concept is so well established that it provides a framework for organizing most of biological knowledge into a coherent picture.

All organisms are similar to and different from other organisms, and some kinds of organisms and individuals have advantages in particular environments (grade 4).

Preferential survival means that differences among individuals in a population affect their ability to survive and reproduce. Classification reflects degrees of relatedness among species (grade 8). Evolution is the consequence of natural selection and differential reproduction. Natural selection and common descent provide the scientific explanation for the history of life on Earth as depicted in the fossil record and as indicated by anatomical and chemical similarities evident within the diversity of existing organisms (grade 12).

Table 9. Life Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Organization and Development: From basic needs of organisms (4) to the levels of organization of living systems (8) to the chemical basis of living systems (12).		
L4.1: Organisms need food,[10] water, and air; a way to dispose of waste; and an environment in which they can live.	**L8.1:** All organisms are composed of cells, from just one cell to many cells. About two thirds of the weight of cells is accounted for by water, which gives cells many of their properties. In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells and function to serve the needs of cells for food, air, and waste removal. The way in which cells function is similar in all living organisms.[11] **L8.2:** Following fertilization, cell division produces a small cluster of cells that then differentiate by appearance and function to form the basic tissues of an embryo.	**L12.1:** Living systems are made of complex molecules (including carbohydrates, fats, proteins, and nucleic acids) that consist mostly of a few elements, especially carbon, hydrogen, oxygen, nitrogen, and phosphorous. **L12.2:** Cellular processes are carried out by many different types of molecules, mostly proteins. Protein molecules are long, usually folded chains made from combinations of amino-acid molecules. Protein molecules assemble fats and carbohydrates and carry out other cellular functions. The function of each protein molecule depends on its specific sequence of amino acids and the shape of the molecule. **L12.3:** Cellular processes are regulated both internally and externally by environments in which cells exist, including local environments that lead to cell differentiation during the development of multicellular organisms. During the development of complex multicellular organisms, cell differentiation is regulated through the expression of different genes.

[10] See p. 51 for a clarification textbox on "Food."

[11] Human organs and organ systems are subsumed under this content statement. See Table 10, Life Science Content Boundaries, for details.

Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Matter and Energy Transformations: From the basic needs of organisms for growth (4) to the role of carbon compounds in growth and metabolism (8) to the chemical basis of matter and energy transformation in living systems (12).		
L4.2: Organisms have basic needs. Animals require air, water, and a source of energy and building material for growth and repair. Plants also require light.	**L8.3:** Cells carry out the many functions needed to sustain life. They grow and divide, thereby producing more cells. Food is used to provide energy for the work that cells do and is a source of the molecular building blocks from which needed materials are assembled. **L8.4:** Plants are producers—they use the energy from light[12] to make sugar molecules from the atoms of carbon dioxide and water. Plants use these sugars, along with minerals from the soil, to form fats, proteins, and carbohydrates. This food can be used immediately, incorporated into the plant's cells as the plant grows, or stored for later use. **L8.5:** All animals, including humans, are consumers, which obtain food by eating other organisms or their products. Consumers break down the structures of the organisms they eat to make the materials they need to grow and function. Decomposers, including bacteria and fungi, use dead organisms or their products for food.	**L12.4:** Plants have the capability (through photosynthesis) to take energy from light to form higher energy sugar molecules containing carbon, hydrogen, and oxygen from lower energy molecules. These sugar molecules can be used to make amino acids and other carbon-containing (organic) molecules and assembled into larger molecules with biological activity (including proteins, DNA, carbohydrates, and fats). **L12.5:** The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in an ecosystem, some energy is stored in newly made structures, but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going. **L12.6:** As matter cycles and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

[12] The phrase "they use the energy from light" does not imply that energy is converted into matter or that energy is lost. See pp. 96-97 for more on energy as Crosscutting Content.

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Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Interdependence: From the interdependence of organisms (4) to specific types of interdependence (8) to consequences of interdependence (12).		
L4.3: Organisms interact and are interdependent in various ways including providing food and shelter to one another. Organisms can survive only in environments in which their needs are met. Some interactions are beneficial; others are detrimental to the organism and other organisms. **L4.4:** When the environment changes, some plants and animals survive and reproduce; others die or move to new locations.	**L8.6:** Two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship. Or, one organism may scavenge or decompose another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other. **L8.7:** The number of organisms and populations an ecosystem can support depends on the biotic resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. **L8.8:** All organisms cause changes in the environment where they live. Some of these changes are detrimental to the organisms or other organisms, whereas others are beneficial.	**L12.7:** Although the interrelationships and interdependence of organisms may generate biological communities in ecosystems that are stable for hundreds or thousands of years, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution. The impact of the human species has major consequences for other species.

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Grade 4	Grade 8	Grade 12
Changes in Living Systems		
Heredity and Reproduction: From life cycles (4) to reproduction and the influence of heredity and the environment on an offspring's characteristics (8) to the molecular basis of heredity (12).		
L4.5: Plants and animals have life cycles. Both plants and animals begin life and develop into adults, reproduce, and eventually die. The details of this life cycle are different for different organisms. **L4.6:** Plants and animals closely resemble their parents.	**L8.9:** Reproduction is a characteristic of all living systems**;** because no individual organism lives forever, reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually. **L8.10:** The characteristics of organisms are influenced by heredity and environment. For some characteristics, inheritance is more important; for other characteristics, interactions with the environment are more important.	**L12.8:** Hereditary information is contained in genes, located in the chromosomes of each cell. A human cell contains many thousands of different genes. One or many genes can determine an inherited trait of an individual, and a single gene can influence more than one trait. **L12.9:** The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment. **L12.10:** Sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

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Grade 4	Grade 8	Grade 12
Changes in Living Systems		
Evolution and Diversity: From differences and adaptations of organisms (4) to preferential survival and relatedness of organisms (8) to the mechanisms of evolutionary change and the history of life on Earth (12).		
L4.7: Different kinds of organisms have characteristics that enable them to survive in different environments. Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.	**L8.11:** Individual organisms with certain traits in particular environments are more likely than others to survive and have offspring. When an environment changes, the advantage or disadvantage of characteristics can change. Extinction of a species occurs when the environment changes and the characteristics of a species are insufficient to allow survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on the Earth no longer exist. **L8.12:** Similarities among organisms are found in anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance.	**L12.11:** Modern ideas about evolution (including natural selection and common descent) provide a scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms. **L12.12:** Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched. **L12.13:** Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection from environmental pressure of those organisms better able to survive and leave offspring.

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Table 10. Life Science Content Boundaries for Grades 4, 8, and 12

	Grade 4	Grade 8	Grade 12
Organization and Development of Living Systems (OD)			
Examples	**L4.OD1:** Common plants and animals that live on land or in water, including vertebrates and insects **L4.OD2:** Food sources for common animals **L4.OD3:** Ways that common animals eliminate waste	**L8.OD1:** Vertebrate animals, including fish **L8.OD2:** Terrestrial and aquatic plants **L8.OD3:** Fungi, bacteria, protests Exclusions: **L8.OD4:** Specific organs and organ systems of invertebrates	**L12.OD1:** Cells and cellular processes in plants and animals
Instruments		**L8.OD5:** Using microscopes to see cells in plant and animal tissues and cell division **L8.OD6:** Relative scale of organs, tissues, cells (not directly measured)	**L12.OD2:** Relative scale of organs, tissues, cells, biomolecules (not directly measured)
Representations		**L8.OD7:** Drawings and photographs of organs and cells of vertebrates **L8.OD8:** Drawings and photographs of developing embryos **L8.OD9:** Drawings showing movement of food, water, oxygen, waste through land plants and vertebrates Exclusions: **L8.OD10:** Drawings of parts of cells	**L12.OD3:** Representations of large biomolecules as polymers of simpler subunits **L12.OD4:** Structural formulas monomers of fats, proteins, carbohydrates (amino acids, fatty acids, simple sugars)

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	Grade 4	Grade 8	Grade 12
Organization and Development of Living Systems (OD)			
Technical Vocabulary	Exclusions: **L4.OD4:** Cells and cellular functions	**L8.OD11:** Specific organs and organ systems of vertebrates: digestive system (esophagus, stomach, intestines, colon); respiratory system (lungs, gills); circulatory system (heart, arteries, veins, capillaries); nervous system (brain, spinal chord, nerves); skeletal system (spine, bones); skin; urinary system (kidneys, bladder) **L8.OD12:** Parts of terrestrial plants: roots, stems, leaves, flowers, seeds Exclusions: **L8.OD13:** Cellular organelles; stages in development of embryos	**L12.OD5:** Generally limited to language of content statements Exclusions: **L12.OD6:** For example, names of cellular organelles or primary, secondary, tertiary structure of proteins, names and functional groups of amino acids
Clarification	**L4.OD5:** Analysis of examples of plants and animals that are familiar to them, explaining how they fulfill four key needs: Food Air Waste disposal Environmental conditions Exclusions: **L4.OD6:** Internal structures and functions in plants and animals	**L8.OD14:** How the structures of organisms work together to fulfill its needs and on the differentiation of cells that occurs during growth and development **L8.OD15:** How organ systems work together physiologically to support the needs of the entire organism, as opposed to the structure and function of specific tissues and cells within organs (e.g., different types of blood cells or muscle cells) Exclusions: **L8.OD16:** The traditional content of systematics, comparing structure and function of different plants and animals	

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	Grade 4	Grade 8	Grade 12
Matter and Energy Transformations in Living Systems (ME)			
Examples	**L4.ME1:** Common plants and animals that live on land or in the water, including vertebrates and insects	**L8.ME1:** Producers, consumers, and decomposers in all five kingdoms **L8.ME2:** Gas exchange in plants, animals, decomposers	**L12.ME1:** Producers, consumers, and decomposers in all five kingdom **L12.ME2:** Representative ecosystems that are widely represented in textbooks and of importance to all students (even those not living near them, e.g., estuaries, farms, temperate forest)
Instruments	**L4.ME2:** Details of movement and external features of plants and animals that reveal how they are taking in materials (and light in the case of plants)	**L8.ME3:** Internal structures of plants and animals responsible for movement of materials **L8.ME4:** Scale of multicellular organisms, cells, molecules Exclusions: **L8.ME5:** Internal structures of plant and animal cells	
Representations	**L4.ME3:** Drawings or photographs showing external organs that take in matter and energy **L4.ME4:** Drawings representing movement of matter and energy into organisms with arrows	**L8.ME6:** Structural formulas of carbon dioxide and water **L8.ME7:** Drawings with arrows showing movements of substances within plants and animals Exclusions: **L8.ME8:** Structural formulas of biomolecules (sugars, fats, amino acids) **L8.ME9:** Drawings with arrows showing movements of substances inside plant and animal cells	**L12.ME3:** Representations of large biomolecules as polymers of simpler subunits **L12.ME4:** Structural formulas monomers of fats, proteins, carbohydrates (amino acids, fatty acids, simple sugars) **L12.ME5:** Chemical equations for overall processes of cellular respiration and photosynthesis **L12.ME6:** General representations of synthesis and decomposition of large biomolecules **L12.ME7:** Diagrams of matter cycling and energy flow in ecosystems Exclusions: **L12.ME8:** Representations of details of synthesis and decomposition (e.g., details of dehydration synthesis)

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	Grade 4	Grade 8	Grade 12
Matter and Energy Transformations in Living Systems (ME)			
Technical Vocabulary	**L4.ME5:** Limited to vocabulary of content statements	**L8.ME10:** Limited to vocabulary of content statements <u>Exclusions:</u> **L8.ME11:** Although these content statements describe the general processes of photosynthesis and cellular respiration, these terms are not included, nor is the word chlorophyll	**L12.ME9:** Vocabulary of content statements **L12.ME10:** Cellular respiration **L12.ME11:** Key elements in biomolecules: carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, sodium <u>Exclusions:</u> **L12.ME12:** Calvin cycle, Krebs cycle, glycolysis, or intermediate products in respiration and photosynthesis
Clarification	**L4.ME6:** Materials or sources of energy (light) that plants and animals take in. Legitimate questions include identifying the sources of these essential materials for different plants and animals	**L8.ME12:** Tracing the sequence of transformations of matter and energy that enable plants and animals to grow and function. **L8.ME13:** Transformations that use or produce gases (e.g., plants growing by incorporating carbon dioxide, animals losing weight by releasing carbon dioxide) are especially significant and difficult for students	**L12.ME13:** Tracking particular atoms or elements (especially carbon) through the processes of photosynthesis, growth, food webs, and cellular respiration at multiple levels: cellular, organismal, and ecological

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	Grade 4	Grade 8	Grade 12
Interdependence of Living Systems (IL)			
Examples	**L4.IL1:** Common plants and animals that live on land or in the water, including vertebrates and insects **L4.IL2:** Environmental conditions and changes in environmental conditions that affect survival of plants and animals, including temperature, shelter, light, food sources, water **L4.IL3:** Interactions among organisms that affect survival, including examples of predation, symbiosis, parasitism	**L8.IL1:** Populations of producers, consumers, and decomposers in all five kingdom **L8.IL2:** Examples of relationships of the types listed in the content statement **L8.IL3:** Examples of disturbances to ecosystems that cause changes in size of populations (e.g., changes in factors listed in content statement, invasive species, human interventions)	**L12.IL1:** Anthropogenic disturbances in ecosystems or environments, including local and global climate change, uses of tilling and pesticides to favor human crops, human land use, harvesting of fish stocks, pollution, invasive species, etc. **L12.IL2:** Natural disturbances in ecosystems such as fires, sedimentation, volcanism, etc. **L12.IL3:** Responses of ecosystems to changes, including succession patterns, alterations due to natural or anthropogenic disturbances
Instruments	**L4.IL4:** Identifying and counting organisms in plots **L4.IL5:** Identifying evidence of interactions (e.g., parasites on plants or animals, evidence of predation) **L4.IL6:** Temperatures on Celsius scale	**L8.IL4:** Measures of population size and density: range, number of individuals per plot	**L12.IL4:** Qualitative descriptions of biodiversity in different ecosystems
Representations	**L4.IL7:** Drawings or photographs of plants, animals, and their interactions	**L8.IL5:** Graphic or geographic representations of size, range, density of populations	**L12.IL5:** Graphic or geographic representations of size, diversity, key species in ecosystems
Technical Vocabulary	**L4.IL8:** Vocabulary of content statements **L4.IL9:** Descriptions of environmental conditions and interactions in non-technical language <u>Exclusions:</u> **L4.IL10:** Predation, symbiosis, parasitism	**L8.IL6:** Vocabulary of content statements	**L12.IL6:** Vocabulary of content statement **L12.IL7:** Descriptions of natural and anthropogenic disturbances (see below)

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	Grade 4	Grade 8	Grade 12
Interdependence of Living Systems (IL)			
Clarification	**L4.IL11:** Interactions of individual plants and animals with their environments or with plants and animals of other species, and how those interactions affect their survival or ability to thrive	**L8.IL7:** Populations, their interactions with other populations and the non-living environment, and how changes in the environment or interactions can affect the size and composition of populations	**L12.IL8:** Ecosystems (including coupled human and natural systems such as farms) as dynamic systems that are constantly changing, especially in response to the large and increasing scale of human impact on ecosystems

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	Grade 4	Grade 8	Grade 12
Heredity and Reproduction (HR)			
Examples	**L4.HR1:** Variety of plant and animal life cycles **L4.HR2:** Descriptions of organisms in terms of characters (e.g., height, eye color, hair color) and traits that are values of those characters (e.g., brown eyes, black hair) **L4.HR3:** People have different external features, such as the size, shape and color of hair, skin, and eyes that resemble their parents	**L8.HR1:** Sexual and asexual reproduction as part of a life cycle of animals, plants, protists, bacteria **L8.HR2:** Effect of nutrition on the characteristics of an organism. Exclusions: **L8.HR3:** Nature vs. nurture	**L12.HR1:** Changes in DNA (mutations) **L12.HR2:** Genetic variation in cells arises from gamete formation and sexual reproduction - inherited traits, intermitted mutations. **L12.HR3:** Basic bioinformatics (DNA fingerprinting, reproductive and therapeutic cloning) Exclusions: **L12.HR4:** Details of transcription and translation. **L12.HR5:** Mendelian genetics **L12.HR6:** Details of meiosis
Instruments		**L8.HR4:** Scale of reproductive cells (sperm and egg) relative to organisms and to other cells	**L12.HR7:** Using microscopes to identify chromosomes **L12.HR8:** Basic principles of electrophoresis Exclusions: **L12.HR9:** PCR
Representations			**L12.HR10:** Double helix **L12.HR11:** Graphic results of electrophoresis Exclusions: **L12.HR12:** Structure of nucleotides **L12.HR13:** Graphic demonstration of mitosis or meiosis

	Grade 4	Grade 8	Grade 12
Heredity and Reproduction (HR)			
Technical Vocabulary	**L4.HR4:** Generally limited to language of content statements and descriptions of organisms in commonly understood terms	**L8.HR5:** Generally limited to language of content statements (e.g., genes, egg, sperm, fertilization) Exclusions: **L8.HR6:** Mendelian genetics (dominant, recessive, etc.) **L8.HR7:** Details of reproduction and development (gamete, zygote, alternation of generations, etc.)	**L12.HR14:** Generally limited to language of content statements (e.g., genes, chromosomes, DNA molecules) Exclusions: **L12.HR15:** Names and structures of nucleotides
Clarification		**L8.HR8:** Every organism has genes: a set of instructions for specifying its traits. Heredity is the passage of these genes from one generation to another. **L8.HR9:** When cells divide, they are reproducing asexually. In asexual reproduction, the new cell (organism) is identical to the parent. **L8.HR10:** In sexual reproduction, a sperm and egg unite (fertilization); half of an individual's traits come from one parent—half from the other.	**L12.HR16:** Every cell in an organism contains a complete genome (DNA), which is maintained from one cell generation to the next by mitosis and DNA replication.

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	Grade 4	Grade 8	Grade 12
Evolution and Diversity of Living Systems (ED)			
Examples	**L4.ED1:** Different plants and animals in the context of their populations and environments **L4.ED2:** Adaptations of plants and animals to their environments **L4.ED3:** Differences among plants and animals in a population	**L8.ED1:** Examples of more and less closely related organisms **L8.ED2:** Examples of fossils and remains of recently extinct organisms **L8.ED3:** Examples of modern changes in populations (e.g., development of insect resistance to pesticides)	
Instruments	**L4.ED4:** Measurements or descriptions of characteristics of plants and animals: height, weight, leaf size, color, etc.	**L8.ED4:** Measurements or descriptions of internal and external structures of organisms	
Representations	**L4.ED5:** Photographs or pictures that show differences among individuals in a population or relationships between organisms and their environments	**L8.ED5:** Photographs or pictures that show differences among individuals in a population in internal or external characteristics	**L12.ED1:** Graphs or tables showing distribution of traits in populations **L12.ED2:** Representations of degree of biochemical similarity in terms of percentages (e.g., 85% of DNA in common)
Technical Vocabulary	**L4.ED6:** Words in common language that describe adaptive traits and traits that differentiate individuals	**L8.ED6:** Adaptation, fitness, evolution **L8.ED7:** Language in content statements <u>Exclusions:</u> **L8.ED8:** Phylogenetic taxonomy (kingdoms, phyla, etc.) **L8.ED9:** Natural selection	**L12.ED3:** Generally limited to vocabulary in content statements

	Grade 4	Grade 8	Grade 12
Evolution and Diversity of Living Systems (ED)			
Clarification	**L4.ED7:** Note that this includes BOTH diversity of species (different species have different traits) and diversity within populations (different individuals in a population have different traits) **L4.ED8:** Describing and comparing individual organisms and reasoning about how their traits can help or hinder their survival	**L8.ED10:** The content statements at this level focus on the process of change in populations through natural selection Fossils and internal and external anatomical evidence of change in populations over time, including extinction and evolutionary change Fossils and internal and external anatomical evidence of relatedness of species <u>Exclusions:</u> **L8.ED11:** Chemical evidence of change in populations over time **L8.ED12:** Chemical evidence or relatedness of species	**L12.ED4:** Students at this level should be asked to produce accounts of changes in populations that include all four of the numbered factors in L12.13.

Earth and Space Science

The past few decades have brought rapid changes in the character of Earth and Space Science. The study of Earth[13] has shifted from surface geology and mining toward global change and Earth systems; and research methods have changed from human observations and mapping to remote sensing and computer modeling. This concept of Earth as a complex and dynamic entity of interrelated subsystems implies that there is no process or phenomenon within the Earth system that occurs in complete isolation from other elements of the system. There has also been a shift in goals, as advances in theory have made it possible to more accurately predict changes in weather and climate, to provide life-saving warnings of floods, hurricanes, earthquakes, and volcanic eruptions, and to understand how human activities influence ecosystem and climate changes across the globe.

In Space Science, similar changes have taken place as a result of new technologies. Successful probes to Mars, Jupiter, and Saturn have vastly expanded knowledge of the solar neighborhood. The discovery of more than 100 planets outside the solar system has raised new questions about the origin of life. Furthermore, advances in ground and space-based telescopes capable of observing many different parts of the electromagnetic spectrum with unprecedented detail have revolutionized understanding of the structure and evolution of the universe itself. In brief, descriptive methods of Earth and Space Science have given way to theory-based inquiry and problem-solving approaches that have far reaching consequences with regard to understanding the universe and stewardship of Planet Earth.

Changes in Earth and Space Science education are beginning to catch up with advances in research. The *National Standards* emphasizes a systems approach to studying Earth, especially at the high school level. Some of today's textbooks pay less attention to describing Earth features and focus instead on a systems perspective in which Earth is viewed as a physical system of interrelated phenomena, processes, and cycles. Some high school curricula have integrated the traditional Earth science disciplines of geology, meteorology, and oceanography with aspects of biology, chemistry, and physics to introduce students to a more holistic study of Earth.

The tools available to students for learning about Earth and space have changed as well. Visualization tools, such as Geographical Information System (GIS) software, have made it possible for Earth Science students to have direct access to the raw data and models used by scientists. Other web-based programs allow students to view and process satellite images of Earth, to direct a camera on board the Space Shuttle, and to access professional telescopes around the world to carry out science projects. In other words, the core concepts, subject matter, and tools used by students have undergone profound changes in recent decades that mirror many of the advances in Earth and Space Science. The data and images gathered by these tools could be used as source materials for assessment items. For example, students could examine data on sea surface temperatures and upper

[13] "Earth" is capitalized, rather than referred to as "the earth," in order to recognize it as one of the planets in the solar system.

atmospheric winds, derived from satellite observations, to predict the intensity and track of a hurricane.

NAEP recognizes that not all of the resources described above are available to all students. Nevertheless, to reflect the importance of this content area, NAEP will include questions about Earth and Space Science at the 4th, 8th, and 12th grade levels. The content statements have been divided into topics and subtopics as summarized in Table 11.

Table 11. Earth and Space Science Content Topics and Subtopics

Earth in Space and Time
Objects in the Universe History of Earth
Earth Structures
Properties of Earth Materials Tectonics
Earth Systems
Energy in Earth Systems Climate and Weather Biogeochemical Cycles

Earth in Space and Time

Earth in Space and Time is divided into two subtopics: Objects in the Universe and History of Earth. The idea that "the universe is large and ancient, on scales staggering to the human mind" (AAAS, 1989, p. 40) connects these subtopics.

One of the earliest discoveries of the scientific age was that Earth is not the center of the universe. It is now known that Earth is a planet in space, one of a family of planets and other bodies that circle a yellow star in a vast galaxy of other stars. Like countless other worlds that are known to exist, Earth has a beginning and a history. That history can be read by carefully and thoughtfully observing the world and the universe.

<u>Objects in the Universe</u>

Objects in the sky, such as the sun and the moon, have patterns of movement. These patterns can be observed through changes in shape or placement in the sky based on time of day or season (grade 4). By recognizing these patterns, people have developed calendars and clocks and explained such phenomena as moon phases, eclipses, and seasons (grade 8).

It was previously thought that Earth was the center of the universe, but it is now known that the sun is the central and largest body in the solar system, which includes Earth and other planets and their moons as well as other objects such as asteroids and comets. Objects in the solar system are kept in predictable motion by the force of gravity (grade 8).

According to the "big bang" theory, the entire contents of the known universe expanded explosively into existence from a hot, dense state 13.7 billion years ago. Early in the history of the universe, stars coalesced out of clouds of hydrogen and helium and clumped together by gravitational attraction into billions of galaxies. When heated to a sufficiently high temperature by gravitational attraction, stars begin nuclear reactions, which convert matter to energy and fuse light elements into heavier ones (grade 12).

History of Earth

Theories of planet formation and radioactive dating of meteorites have led to the conclusion that the sun, Earth and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. Early Earth was very different from today's planet. Initially, there was no life and no molecular oxygen in the atmosphere. There is evidence that one-celled organisms—the bacteria—were the first forms of life on our planet, appearing about 3.5 billion years ago. These bacteria are thought to be responsible for adding oxygen to Earth's atmosphere, making it possible for a wider diversity of life forms to evolve (grade 12).

Earth processes seen today, such as erosion and mountain building, have made possible the measurement of geologic time though methods such as observing rock sequences and using fossils to correlate the sequences at various locations. Fossils also provide evidence of how life and environmental conditions have changed (grade 8). Early methods of determining geological time, such as the use of index fossils and stratigraphic sequences allowed for the relative dating of geologic events. However, absolute dating was impossible until the discovery that certain radioactive isotopes in rocks have known decay rates, making it possible to determine how many years ago a given rock sample formed (grade 12).

Earth's surface changes over time. Some changes are due to slow processes, such as erosion and weathering; and others are due to rapid processes such as volcanic eruptions, landslides, and earthquakes (grade 4). Changes caused by violent earthquakes and volcanic eruptions can be observed on a human time scale, but many geological processes, such as the building of mountain chains and shifting of entire continents, take place over hundreds of millions of years. Water, ice, waves, and wind sculpt Earth's surface to produce distinctive landforms (grade 12).

Earth Structures

Content statements related to Earth Structures fall into two subtopics: Properties of Earth Materials and Tectonics. The study of Earth materials has contributed to understanding dynamic processes, which are, in turn, driven by the movement of vast tectonic plates. Conversely, the development of tectonic theory has made it possible to locate and extract Earth materials for a wide variety of human uses.

Properties of Earth Materials

Earth materials that occur in nature include rocks, minerals, soils, water, and the gases of the atmosphere. Natural materials have different properties, which sustain plant and animal life (grade 4). Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers, with each having a different chemical composition and texture (grade 8). Some Earth materials have properties that make them useful either in their present form or designed and modified to solve human problems and enhance the quality of life (grade 4).

Rocks and rock formations bear evidence of the conditions and forces that created them, ranging from the violent conditions of volcanic eruptions to the slow deposition of sediments. The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has a different physical and chemical composition at different elevations (grade 8).

Tectonics

A basic understanding of geological history, described above, forms the foundation for later understanding of tectonics (grade 4). Earth's internal structure is layered with a lithosphere, hot convecting mantle, and dense metallic core. Lithospheric plates, on the scale of continents and oceans, constantly move at rates of centimeters per year, in response to movements in the mantle. Major geological events such as earthquakes, volcanic eruptions, and mountain building result from these plate motions (grade 8).

Although continental drift was first suggested as early as the late 16th century and further developed in the early 1900s, it was not widely accepted until more convincing evidence emerged as a result of extensive exploration of the sea floor. By the late 1960s, mapping of the Mid-Atlantic Ridge, evidence of sea floor spreading, and subduction led to the more general theory of plate tectonics. The current explanation is that the outward transfer of Earth's internal heat propels the plates comprising Earth's surface across the face of the globe, pushing the plates apart where magma rises to form mid-ocean ridges, and pulling the edges of plates back down where Earth materials sink into the crust at deep trenches (grade 12).

Earth as a whole has a magnetic field that is detectable at the surface with a compass. Earth's magnetic field is similar to the field of a natural or human-made magnet with north and south poles and lines of force. For thousands of years, people have used

compasses to aid navigation on land and sea (grade 8). Crucial evidence in support of tectonic theory came from studies of the magnetic properties of rocks on the ocean floor (grade 12).

Earth Systems

Earth Systems science is organized according to three subtopics: Energy in Earth Systems, Climate and Weather, and Biogeochemical Cycles. The explorers of the 16th century who circumnavigated the planet were the first to become aware of global weather and climate patterns. As science began to mature and diversify in the 19th and 20th centuries, those who scientifically studied the planet did so from the perspective of the traditional disciplines, such as geology, oceanography, and meteorology. Currently, working with vastly improved technologies, most scientists take an Earth systems perspective, including the study of how energy moves through Earth systems and the integration of disciplines to better understand Earth's biogeochemical cycles.

<u>Energy in Earth Systems</u>

The sun warms the land, air, and water and helps plants grow (grade 4). The sun is the major source of energy for phenomena on Earth's surface. The sun drives convection within the atmosphere and oceans, producing winds, ocean currents, and the water cycle. Seasons result from annual variations in the intensity of sunlight and length of day due to the tilt of Earth's rotation axis relative to the plane of its yearly orbit around the sun (grade 8).

Earth's systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational/thermal energy from Earth's original formation (grade 12).

<u>Climate and Weather</u>

Weather changes from day to day and over the seasons. Scientists use tools for recording and predicting weather changes (grade 4). Global patterns of atmospheric movement influence local weather (grade 8).

Climate is determined by energy transfer from the sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover, atmospheric gases, and Earth's rotation, as well as static conditions such as the position of mountain ranges and oceans, seas, and lakes (grade 12). Oceans have a major effect on climate because water in the oceans holds a large amount of heat (grade 8).

<u>Biogeochemical Cycles</u>

Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical forms. Elements move

within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of biogeochemical cycles (see textbox that follows). Movement of matter through Earth's systems is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in coal and other fossil fuels, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life (grade 12).

Water, which covers the majority of Earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle." Water evaporates from Earth's surface, rises and cools as it moves to higher elevations, condenses as clouds, falls as rain or snow, and collects in lakes, oceans, soil, and underground (grade 8).

Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients (grade 12). The supply of many Earth resources such as fuels, metals, fresh water, and farmland is limited.

Humans change environments in ways that can either be beneficial or detrimental for themselves and other organisms (grade 4). Humans have devised methods for extending the use of Earth resources through recycling, reuse, and renewal (grade 4). However, other activities—reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming—have changed Earth's land, oceans, and atmosphere. Studies of plant and animal populations have shown that such activities can reduce the number and variety of wild plants and animals and sometimes result in the extinction of species (grade 8).

Table 12. Earth and Space Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Earth in Space and Time		
Objects in the Universe: From patterns in the sky (4) to a model of the solar system (8) to a vision of the universe (12).		
E4.1: Objects in the sky have patterns of movement. The sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons. The moon appears to move across the sky on a daily basis much like the sun. **E4.2:** The observable shape of the moon changes from day to day in a cycle that lasts about a month.	**E8.1:** In contrast to an earlier theory that Earth is the center of the universe, it is now known that the sun, an average star, is the central and largest body in the solar system. Earth is the third planet from the sun in a system that includes eight other planets and their moons, as well as smaller objects, such as asteroids and comets. **E8.2:** Gravity is the force that keeps most objects in the solar system in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.	**E12.1:** The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin approximately 13.7 billion years ago when the universe began in a hot dense state. According to this theory, the universe has been expanding ever since. **E12.2:** Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars and billions of galaxies. **E12.3:** Stars, like the sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. These and other processes in stars have led to the formation of all the other elements.

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Grade 4	Grade 8	Grade 12
Earth in Space and Time		
History of Earth: From evidence of change (4) to estimating the timing and sequence of geologic events (8) to theories about Earth's history (12).		
E4.3: The surface of Earth changes. Some changes are due to slow processes, such as erosion and weathering, and some changes are due to rapid processes, such as landslides, volcanic eruptions, and earthquakes.	**E8.3:** Fossils provide important evidence of how life and environmental conditions have changed in a given location. **E8.4:** Earth processes seen today, such as erosion and mountain building, made possible the measurement of geologic time through methods such as observing rock sequences and using fossils to correlate the sequences at various locations.	**E12.4:** Early methods of determining geologic time, such as the use of index fossils and stratigraphic sequences, allowed for the relative dating of geological events. However, absolute dating was impossible until the discovery that certain radioactive isotopes in rocks have known decay rates, making it possible to determine how many years ago a given rock sample formed. **E12.5:** Theories of planet formation and radioactive dating of meteorites and lunar samples have led to the conclusion that the sun, Earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. **E12.6:** Early Earth was very different from today's planet. Evidence for one-celled forms of life—the bacteria—extends back more than 3.5 billion years. The evolution of life caused dramatic changes in the composition of Earth's atmosphere, which did not originally contain molecular oxygen. **E12.7:** Earth's current structure has been influenced by both sporadic and gradual events. Changes caused by violent earthquakes and volcanic eruptions can be observed on a human time scale, but many geological processes, such as the building of mountain chains and shifting of entire continents, take place over hundreds of millions of years.

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Grade 4	Grade 8	Grade 12
Earth Structures		
Properties of Earth Materials: From natural and human-made materials (4) to soil analysis and layers of the atmosphere (8)		
E4.4: Earth materials that occur in nature include rocks, minerals, soils, water, and the gases of the atmosphere. **E4.5:** Natural materials have different properties, which sustain plant and animal life. **E4.6:** Some Earth materials have properties that make them useful either in their present form or designed and modified to solve human problems and enhance the quality of life, as in the case of materials used for building or fuels used for heating and transportation.	**E8.5:** Rocks and rock formations bear evidence of the minerals, materials, temperature/pressure conditions, and forces that created them. Some formations show evidence that they were deposited by volcanic eruptions. Others are composed of sand and smaller particles buried and cemented by dissolved minerals to form solid rock again. Still others show evidence that they were once earlier rock types that were exposed to heat and pressure until they changed shape and in some cases melted and recrystallized. **E8.6:** Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers, with each having a different chemical composition and texture. **E8.7:** The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has a different physical and chemical composition at different elevations.	

Grade 4	Grade 8	Grade 12
Earth Structures		
Tectonics: From the basics of tectonic theory and Earth magnetism (8) to the physical mechanism that drives tectonics and its supporting evidence (12)		
	E8.8: The Earth is layered with a lithosphere; hot, convecting mantle; and dense, metallic core. **E8.9:** Lithospheric plates on the scale of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions. **E8.10:** Earth as a whole has a magnetic field that is detectable at the surface with a compass. Earth's magnetic field is similar to the field of a natural or human-made magnet with north and south poles and lines of force. For thousands of years, people have used compasses to aid in navigation on land and sea.	**E12.8:** Mapping of the Mid-Atlantic Ridge, evidence of sea floor spreading, and subduction provided crucial evidence in support of the theory of plate tectonics. The theory currently explains plate motion as follows: the outward transfer of Earth's internal heat propels the plates comprising Earth's surface across the face of the globe. Plates are pushed apart where magma rises to form mid-ocean ridges, and the edges of plates are pulled back down where Earth materials sink into the crust at deep trenches.

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Grade 4	Grade 8	Grade 12
Earth Systems		
Energy in Earth Systems: From role of the sun (4) to the sun's observable effects (8) to internal and external sources of energy in Earth systems (12).		
E4.7: The sun warms the land, air, and water and helps plants grow.	**E8.11:** The sun is the major source of energy for phenomena on Earth's surface. The sun provides energy for plants to grow and drives convection within the atmosphere and oceans, producing winds, ocean currents, and the water cycle. **E8.12:** Seasons result from annual variations in the intensity of sunlight and length of day, due to the tilt of Earth's rotation axis relative to the plane of its yearly orbit around the sun.	**E12.9:** Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from Earth's original formation.
Climate and Weather: From local weather (4) to global weather patterns (8) to systems that influence climate (12).		
E4.8: Weather changes from day to day and over the seasons. **E4.9:** Scientists use tools for observing, recording, and predicting weather changes from day to day and over the seasons.	**E8.13:** Global patterns of atmospheric movement influence local weather. Oceans have a major effect on climate because water in the oceans holds a large amount of heat.	**E12.10:** Climate is determined by energy transfer from the sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover, atmospheric gases, and Earth's rotation, as well as static conditions such as the positions of mountain ranges and of oceans, seas, and lakes.

Grade 4	Grade 8	Grade 12
Earth Systems		
Biogeochemical Cycles: From uses of Earth resources (4) to natural and human-induced changes in Earth materials and systems (8) to biogeochemical cycles in Earth systems (12).		
E4.10: The supply of many Earth resources such as fuels, metals, fresh water, and farmland is limited. Humans have devised methods for extending the use of Earth resources through recycling, reuse, and renewal. **E4.11:** Humans depend on their natural and constructed environment. Humans change environments in ways that can either be beneficial or detrimental for themselves and other organisms.	**E8.14:** Water, which covers the majority of Earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle." Water evaporates from Earth's surface, rises and cools as it moves to higher elevations, condenses as clouds, falls as rain or snow, and collects in lakes, oceans, soil, and underground. **E8.15:** Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed Earth's land, oceans, and atmosphere. Studies of plant and animal populations have shown that such activities can reduce the number and variety of wild plants and animals and sometimes result in the extinction of species.	**E12.11:** Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Most elements can exist in several different chemical forms. Earth elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of biogeochemical cycles. **E12.12:** Movement of matter through Earth's systems is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in coal and other fossil fuels, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life. **E12.13:** Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients.

Table 13. Earth and Space Science Content Boundaries for Grades 4, 8, and 12

	Grade 4	Grade 8	Grade 12
Objects in the Universe (OU)			
Examples	**E4.OU1:** In the morning, the sun is generally to the east; at noon it is toward the south; and during the afternoon, it is to the west. It is never directly overhead. **E4.OU2:** The moon's appearance during the day and at night, and its daily path across the sky. Proper sequencing of pictures of moon phases during the month. Exclusions: **E4.OU3:** Clouds, birds, or airplanes (since the intention of these statements is to introduce students to "Objects in the Universe") **E4.OU4:** Observations of stars and galaxies.	**E8.OU1:** Earth-Sun-Moon System: The space perspective to explain the day-night cycle, moon phases, solar and lunar eclipses, seasons and tides. Distinction between explanation for moon phases and that for a lunar eclipse. Reason for seasons includes: seeing different constellations at different times of year, and explaining changes in length of day and temperature during the year. **E8.OU2:** Solar System: Relative sizes and distances of planets, the differences between terrestrial planets (including our Earth) and gas giant planets, and shapes of orbits (ellipses of varying eccentricity). **E8.OU3:** Gravity pulls things "down," towards the center of the Earth. It acts between all objects, and operates across empty space to keep planets and satellites in their orbits. Astronauts in orbit experience gravity as they "fall" around Earth. (A common naïve conception is that there is no gravity in space because there is no air there.) Exclusions: **E8.OU4:** Mathematical formulation of Kepler's laws or the equations for elliptical orbits or parabolic trajectories.	**E12.OU1:** History of universe: Limited to major features of big bang theory. **E12.OU2:** Structure of universe: Location of our galaxy among others, and role of gravity in galaxy formation. **E12.OU3:** Origin of elements: Key ideas are formation of H and He in early universe, and formation of heavier elements by fusion in stars. **E12.OU4:** Processes in stars: Qualitative understanding about nuclear fusion in stars that release energy and produce heavier elements. Exclusions: **E12.OU5:** Details of the big bang such as "inflation" or "decoupling". **E12.OU6:** Reaction rates in stars **E12.OU7:** How galaxies are organized into larger structures **E12.OU8:** Details of nuclear reactions.

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	Grade 4	Grade 8	Grade 12
	Objects in the Universe (OU)		
Instruments	**E4.OU5:** It is challenging to find patterns in the sun's movement because it is too bright to observe directly. To counter this problem, shadows of a vertical stick placed in the ground may be observed. Or, a flagpole or other vertical object can mark the position of the shadow at regular intervals during the day. **E4.OU6:** Most important observations of the moon are to record monthly cycle of moon phases. The moon is sometimes seen during the day; it moves slowly across the sky like the sun; and (when the moon can be seen during the day) the lighted side faces the sun. Exclusions: **E4.OU7:** Telescope.	**E8.OU5:** Naked eye: daytime and early evening observations of sun, moon and planets, including how moon phases are related to distance between sun and moon, how sun's path in the sky changes with seasons, and how planets gradually move among stars. Record observations with sketches. Use "fists" to measure the angular distance between sun and moon. **E8.OU6:** Telescopes and binoculars: appearance of lunar craters, mountains, and large dark areas on the moon; difference between how stars and planets appear in telescopes or binoculars. Exclusions: **E8.OU7:** Inverse square relationship of gravity and distance.	**E12.OU9:** Appearance of stars, nebulae, and galaxies through telescopes and binoculars; images taken by professional telescopes **E12.OU10:** Evidence provided by spectroscopes to determine the composition of stars as well as the speed of stars and galaxies towards or away from us. **E12.OU11:** How scientists use computers to simulate the Big Bang and galactic formation. **E12.OU12:** How results are derived from above instruments and used as evidence. Exclusions: **E12.OU13:** How to operate above instruments
Representations	**E4.OU8:** Simple sketches showing the movement of a gnomon's shadow, the path of the sun, moon phases, or changing position and appearance of the moon. **E4.OU9:** Application of knowledge of sun's daily path to the design of houses or position of solar panels to take full advantage of solar radiation.	**E8.OU8:** Solar system and gravity—may include drawings to represent spatial relationships and/or student data. **E8.OU9:** Gravity—satellites, rockets, or other space technologies. **E8.OU10:** Mathematics concepts (ellipses, angular measures, and scale) should use conventional notation.	**E12.OU14:** How technology provides evidence to test theories about stars and the universe (may use images taken by large or space-based telescopes and spectra of stars and galaxies) **E12.OU15:** Interpretation of graphs in terms of relationships (e.g., brightness vs. temperature [HR Diagram], distance to galaxies vs. red shift [Hubble's Law]) Exclusions: **E12.OU16:** Naming laws represented by graphs (e.g., Hubble's Law)
Technical Vocabulary	**E4.OU10:** Limited to terms in the content statement, or in everyday usage, but related to the sky (as in "path of the sun" rather than ecliptic, or "vertical stick" rather than gnomon).	**E8.OU11:** Common terms in astronomy included, such as trajectory, orbit, and eclipse, and angular measurement in degrees Exclusions: **E8.OU12:** Technical terms nonessential for conceptual understanding, such as apogee and perigee.	**E12.OU17:** Technical vocabulary from physics and chemistry questions as well as commonly used astronomical terms such as galaxy, nebula, and supernova. Exclusions: **E12.OU18:** Exotic objects such as neutron stars or black holes

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	Grade 4	Grade 8	Grade 12
Objects in the Universe (OU)			
Clarification	**E4.OU11:** Changes and patterns in the sky from an earth-centric viewpoint. <u>Exclusions:</u> **E4.OU12:** The space perspective in explaining these patterns.	**E8.OU13:** The space perspective of the solar system to explain phenomena such as moon phases and seasons. <u>Exclusions:</u> **E8.OU14:** Underlying physics principles of above phenomena	**E12.OU19:** Observational evidence and physics concepts that support theories about how stars shine and the origin of the universe <u>Exclusions:</u> **E12.OU20:** Phenomena such as neutron stars or black holes.

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	Grade 4	Grade 8	Grade 12
	History of Earth (HE)		
Examples	**E4.HE1:** Processes that break down earth structures, such as mountains are worn down gradually as rocks are weathered and eroded, and rapidly when landslides occur. **E4.HE2:** Processes that build up earth structures and materials, such as the slow formation of soils and sedimentary rocks when rivers and streams deposit sand and mud; or the rapid buildup (or destruction) of mountains during volcanic eruptions, or uplift of large land masses during earthquakes. Exclusions: **E4.HE3:** Names of the processes (focus should be on the processes themselves). For example, it is not important that students distinguish between weathering and erosion.	**E8.HE1:** Order of events based on images or drawings of road cuts, cores, or other evidence; evidence of more recent events can be found closer to the surface. (Law of superposition). **E8.HE2:** Data on rate of deposition can be extrapolated to determine how long it took a thick layer of sediment to form. (keeping numbers simple) **E8.HE3:** How scientists are able to reconstruct not only extinct animals, but also past environments (using fossils). **E8.HE4:** How conditions changed over time (a cluster of items may tap this well) Exclusions: **E8.HE5:** Names of the processes (focus should be on the processes themselves). For example, students should not be asked to name the Law of Superposition, but they should be expected to understand and apply it.	**E12.HE1:** How to use index fossils to determine time sequences and how to use half-life of radioactive isotopes to determine time spans. **E12.HE2:** Key phases in the geologic evolution of Earth, e.g., formation of the planet more than 4 billion years ago, evolution of single-celled animals more than 3 billion years ago, development of an atmosphere with oxygen about 2 billion years ago, multi-celled animals less than 1 billion years ago. **E12.HE3:** Simple quantitative problems based on measured rates of geologic processes, such as mountain-building, deposition, or erosion; calculations of how long it took for major geologic changes to occur. Exclusions: **E12.HE4:** Naming the processes or understanding the detailed mechanism of radioactive decay (emphasis should be on the use of these processes to solve geologic puzzles).
Instruments	**E4.HE4:** Laboratory experiments or computer simulations of processes that change earth structures and materials. **E4.HE5:** Images taken at different points in time.	**E8.HE6:** Simple mechanical coring instruments used to extract a sample of a lake bed or other column, revealing the history of deposition over time. **E8.HE7:** Simple calculations of time spans given data on rate of deposition. **E8.HE8:** Interpretation of fossil replicas (or images of fossils)	**E12.HE5:** Data on radioactive isotope decay can be presented in graph form and used as a tool to determine the age of a rock sample given percentages of different elements in the rock. **E12.HE6:** Drawing of rock layers with the location of fossils from an extinct prehistoric animal, along with dates of volcanic rock layers determined by radioisotope methods, can be used to give upper and lower bounds of time during which the extinct animal lived.

	Grade 4	Grade 8	Grade 12
History of Earth (HE)			
Representations	**E4.HE6:** Pictures showing how earth structures have changed over time (students can identify the processes that were likely to have caused those changes)	**E8.HE9:** Drawings, images, charts and graphs can be used for paper-and-pencil items. **E8.HE10:** Rock samples and fossil replicas can be used for hands-on tasks. **E8.HE11:** Computer simulations showing changes in earth structures over time can be used for IT tests.	**E12.HE7:** Illustrations of rock sequences, drawings of index fossils, and computer simulations of radioactive decay (can be used to assess understanding of how to measure geologic time). **E12.HE8:** Charts of long time spans (can be used to assess understanding of the sequence and approximate timeframe for changes in Earth history).
Technical Vocabulary	**E4.HE7:** Limited to terms in the content statement or in everyday use.	**E8.HE12:** Common terms in geology (e.g. sedimentation) and paleontology (e.g. fossils) . Can use names of Eras (Pre-Cambrian, Paleozoic, Mesozoic and Cenozoic). Exclusions: **E8.HE13:** Names of extinct animals identified by their fossils, except for the most common such as trilobites and better-known dinosaurs. **E8.HE14:** Names of geologic Periods and epochs.	**E12.HE9:** Technical vocabulary associated with geology (e.g. index fossils) as well as relevant terms from life sciences (bacteria, algae, extinct) and physics (radioisotopes, half-life). **E12.HE10:** Can use names of Eras (Pre-Cambrian, Paleozoic, Mesozoic and Cenozoic) and geologic Periods (Cambrian, Carboniferous, etc.) Exclusions: **E12.HE11:** Names of specific life forms (stromatolites, etc.) **E12.HE12:** Geologic epochs.
Clarification	**E4.HE8:** Some changes in Earth's surface take place rapidly and others take place slowly in terms of a human lifetime Exclusions: **E4.HE9:** Changes that take place over extremely long stretches of time, i.e., students' grasp of vast span of geologic time.	**E8.HE15:** Students are better able to grasp large spans of time. Focus should be on the evidence (fossils, rock sequences, etc.) that enable scientists to "read" earth history.	**E12.HE13:** More sophisticated evidence for measuring geologic time and determining a sequence of events. Revisit mechanisms that build up and tear down Earth structures; sources of evidence and vast span of geologic time.

	Grade 4	Grade 8	Grade 12
	Properties of Earth Materials (PE)		
Examples	**E4.PE1:** Common objects related to fuels (oil, natural gas, wood [plants]); building materials (wood, cement, stone, grasses, bricks); food production (air, water, soil); metals and gems (rocks and ores, diamonds, rubies, emeralds) **E4.PE2:** Shelter for animals: trees, bushes, soil, caves **E4.PE3:** Conditions under which water is solid (ice) or gas (water vapor). **E4.PE4:** Soil is a medium for plant growth; soil living animals (worms, bugs, ants, moles) help in decomposition (rotting) of dead plants and animals. **E4.PE5:** Soil may contain rock fragments, sand, clay, silt, organic material and water. Different soils have different amounts (%) of these materials. <u>Exclusions:</u> **E4.PE6:** Carbon dioxide	**E8.PE1:** Relating types of rock to conditions of formation, e.g., sandstone to moving water (rivers, beaches); shale to standing water (lakes, ponds); limestone to precipitation in shallow constricted basins (coves, gulfs, bays, lakes, ponds); coal to bogs and swamps **E8.PE2:** Granite (magma) intrusive igneous, basalt (lava) extrusive igneous **E8.PE3:** Metamorphic rocks: Heat and pressure. Contact metamorphism by heat (rising magma); regional metamorphism by heat and pressure (tectonics collision of plates) **E8.PE4:** Atmosphere: clouds layer close to Earth's surface—troposphere (location of weather and wind), stratosphere (location of ozone layer), ozone (03) layer (absorbs ultraviolet light) **E8.PE5:** Atmosphere is a mixture of gases (approx. 70% nitrogen, 20% oxygen, 4% water vapor; 6% all other gases) **E8.PE6:** Sources of natural fuels: oil, natural gas, peat, bituminous coal, anthracite coal **E8.PE7:** With elevation in atmosphere, temperature decreases and air pressure decreases <u>Exclusions:</u> **E8.PE8:** Names of instrusive magma bodies, e.g., batholith **E8.PE9:** Names of extrusive lava bodies, e.g., sills, dikes **E8.PE10:** Specific names of other atmosphere layers, e.g., thermosphere, ionosphere	[No content statements at this grade.]

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	Grade 4	Grade 8	Grade 12
	Properties of Earth Materials (PE)		
Instruments	**E4.PE7:** Classification of Earth or Human-made materials **E4.PE8:** Qualitative descriptions of how earth materials are used in houses **E4.PE9:** Qualitative descriptions of how to separate earth materials **E4.PE10:** Qualitative/quantitative critique of experiments (e.g., determining drainage ability of three soil types)	**E8.PE11:** Quantitative measures of mineral hardness using Moh's Hardness Scale **E8.PE12:** Quantitative measures of soil porosity and permeability **E8.PE13:** Quantitative measures of sediment size using sieves **E8.PE14:** Litmus paper test of soils acidity/alkalinity	[No content statements at this grade.]
Representations	**E4.PE11:** Simple bar graphs and tables, pictures and diagrams	**E8.PE15:** Topographic, geologic and physical geographic maps **E8.PE16:** Pie charts, bar graphs, **E8.PE17:** Drawings on stratigraphic sequences	[No content statements at this grade.]
Technical Vocabulary	**E4.PE12:** Generally limited to common natural materials, e.g., sand, clay, pebbles, oil, natural gas, stone, wood, grasses, rocks, minerals, gems (diamonds, rubies, emeralds). **E4.PE13:** Generally limited to common man-made materials, e.g., bricks, tiles, cement, aluminum poles, nails, wire	**E8.PE18:** Sedimentary rock (sandstone, limestone, shale, coal, salt); igneous rock (granite, basalt, pumice, ash); metamorphic rock (marble, gneiss, schist, coal) **E8.PE19:** Ores: iron, zinc, uranium, aluminum, copper, coal **E8.PE20:** Soil type and profile is governed by bedrock type, weathering, erosion, climate. **E8.PE21:** Soil textures (silt/loam/sand); pH of soil (acidic/alkaline) <u>Exclusions:</u> **E8.PE22:** Ores: rare earth (e.g., titanium), alloys (e.g., bronze, steel, pewter, ceramics) **E8.PE23:** Soils: names of soils, pH scale	[No content statements at this grade.]

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	Grade 4	Grade 8	Grade 12
	Properties of Earth Materials (PE)		
Clarification	**E4.PE14:** Distinguishing Earth materials and their properties from man-made materials. How humans and other animals use Earth materials for food, shelter, and tools.	**E8.PE24:** More in-depth properties (physical and chemical) of Earth materials and the atmosphere. The information in rocks, minerals, and soils can be used to "tell a story" about the environment of formation. Maps are tools to be used to interpret the "rock stories." <u>Exclusions:</u> **E8.PE25:** Core concepts about physics and chemistry, e.g., chemical reactions, stress and strain	[No content statements at this grade.]

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	Grade 4	Grade 8	Grade 12
Tectonics (TE)			
Examples	[No content statements at this grade.]	**E8.TE1:** Common geographic structures related to plate boundaries, e.g., Pacific ring of fire, deep-sea trenches, and volcanoes with subduction plate boundaries. **E8.TE2:** Earth surface features that represent evidence for Continental Drift, e.g., matching continent shapes, matching rock formations **E8.TE3:** Depth of earthquakes (focus) related to plate boundaries, e.g., shallow focus only = spreading boundary or slip/slide boundary. **E8.TE4:** Location of major mountain chains on a geographic map **E8.TE5:** Distinction between igneous mountains (Andes, Cascades) and uplifted/folded/faulted mountains (Rockies, Alps, Himalayans) and their relation to plate movements, respectively subduction zone and continental collision boundaries **E8.TE6:** Geographic north and magnetic north are different, topographic maps have a notation for the correction.	**E12.TE1:** Mechanism of convection current in the mantle and athenosphere to account for plate movements **E12.TE2:** Distinction between less dense continental crust (lithosphere) and more dense oceanic crust (athenosphere) **E12.TE3:** Historical events, evidence and arguments for continental drift (A. Wegner). Fossils, rock formations, continental fit – Pangea **E12.TE4:** Historical events, evidence, and arguments for sea-floor spreading (H. Hess) and Plate Tectonics (J. Tuzo Wilson). **E12.TE5:** Paleomagnetism in rocks and ocean-floor as evidence for movement of continents. **E12.TE6:** Relationship between orogenic (mountain building) events and plate tectonic movements of continents colliding. **E12.TE7:** The inclination and declination of a compass needle changes with latitude and longitude locations.
Instruments	[No content statements at this grade.]	**E8.TE7:** Qualitative descriptions of plate/continent motions to account for major orogenic and volcanic events. **E8.TE8:** Quantitative measures of earthquake locations, frequencies and intensities.	**E12.TE8:** Calculation of rate of plate motion using age of rock and distance from spreading ridge. **E12.TE9:** Calculation of discrepancy between oldest age of ocean floor rocks and continental rocks.

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	Grade 4	Grade 8	Grade 12
Tectonics (TE)			
Representations	[No content statements at this grade.]	**E8.TE9:** Topographic maps to distinguish high and low elevations, floodplains, drainage basins. **E8.TE10:** Geologic maps to locate and interpret rock formations and rock sequence, e.g., igneous activity, sedimentary processes, metamorphism **E8.TE11:** Physical geographic maps to locate ocean bottom and continental features aligned with plate boundaries **E8.TE12:** Earthquake maps to locate patterns of earthquakes. **E8.TE13:** Models/representations of Earth's Interior and Earth's Magnetic Field	**E12.TE10:** Topographic maps to construct elevation profile. **E12.TE11:** GIS data, representations, and models or map projections to align earthquake foci with plate boundaries **E12.TE12:** GIS data, representations, and models or map projections to locate microplates **E12.TE13:** GIS data, representations, and models or map projections to align ores with tectonic activity
Technical Vocabulary	[No content statements at this grade.]	**E8.TE14:** Generally limited to the vocabulary in the content statements, with addition of names of major continents and oceans; names of plate boundaries, e.g., mid-ocean ridge, subduction zone **E8.TE15:** Paleozoic, Mesozoic, and Cenozoic Eras Exclusions: **E8.TE16:** Geologic periods and epochs.	**E12.TE14:** Generally limited to the vocabulary in the content statements, with addition of convection and paleomagnetism. **E12.TE15:** Paleozoic, Mesozoic, and Cenozoic Eras. **E12.TE16:** Names of geologic Periods (Cambrian, Carboniferous, etc.) Exclusions: **E12.TE17:** Geologic epochs.
Clarification	[No content statements at this grade.]	**E8.TE17:** Correlation among plate boundaries, earthquakes and geographic features. Reading and interpreting maps—physical, topographic and geologic.	**E12.TE18:** Historical and contemporary models, mechanisms, and theories associated with tectonics. Evidence for the support of the models, mechanisms, and theories. Reading and interpreting maps and GIS information.

	Grade 4	Grade 8	Grade 12
	Energy in Earth Systems (EE)		
Examples	**E4.EE1:** Sunlight is a source of heat for the planet Earth; sunlight causes evaporation of water; sunlight melts snow and ice; sunlight is needed for plant growth **E4.EE2:** Land (soil, rocks) absorbs and loses heat faster than water. **E4.EE3:** Warmer air/water rises; colder air sinks; cold at higher elevations; rising and sinking air and water create convection cells/currents **E4.EE4:** Warm at Equator; cold at the Poles	**E8.EE1:** Sunlight can penetrate to a water depth of 100m, regulating and restricting plant/algae growth to shallow depths **E8.EE2:** Warm and cold air and water drive convention currents in the atmosphere and the oceans. **E8.EE3:** Winds are the result of convection currents between high and low temperature regions (e.g., shore breezes) **E8.EE4:** Earth has seasons **E8.EE5:** Earth's tilt of axis (23.5º) is oriented in the same direction, causing the north pole to face the sun from March 21 to September 21; and the south pole to face the sun from September 21 to March 21 (spring and autumnal equinox). **E8.EE6:** The amount of daylight hours changes from day to day, getting shorter/longer in the northern/southern hemisphere from June 21 to Dec 21 and longer from Dec 21 to June 21 (summer and winter solstice). **E8.EE7:** Major currents: Jet Stream, Gulf Stream, El Nino **E8.EE8:** Atmosphere (clouds) reflects and absorbs incoming solar radiation; increased % of CO2 in atmosphere correlates with increase in global atmospheric and oceanic temperature; trapped heat causes rise in temperature. **E8.EE9:** Angle of the sun/height of sun in the sky changes from day to day—lower June 21 - Dec 21 and higher Dec 21 - June 21. **E8.EE10:** The higher the sun is in the sky, the more intense is the heat from the sunlight.	**E12.EE1:** Earth has internal sources of heat: radioactive decay (e.g., Kimberlite in South Africa—formation of diamonds); latent heat in the Earth from initial formation of the planet **E12.EE2:** The model of the Earth contains a liquid magma core. **E12.EE3:** Friction from colliding/faulting/folding crust and subducting plates: magma for formation of island arcs/volcanoes (e.g., Mt. St. Helens, Mt Fuji; Mt. Etna, Krakatoa); geothermal activity (hot springs, geysers) **E12.EE4:** Friction from upwelling spreading plates: mid-oceanic ridge lava flows (e.g., Iceland, Azores, Galapagos Is.)

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	Grade 4	Grade 8	Grade 12
	Energy in Earth Systems (EE)		
Instruments	**E4.EE5:** Temperature measures (e.g., of bottled water—one left in sunlight, one left in shade) **E4.EE6:** Location on map projections of hot desert regions and cold snow-covered mountainous regions	**E8.EE11:** Measurement of the length of shadows over intervals of months **E8.EE12:** Measurement of the location of sunrise and sunset on the horizon **E8.EE13:** Calculation of incoming solar radiation	
Representations	**E4.EE7:** Drawings of convection cells: warm air and water rise, cold air and water sink **E4.EE8:** Charts or bar graphs reflecting variations in annual temperature measurements to show seasons.	**E8.EE14:** Drawings of the Earth–Sun model: revolution, rotation, tilt-of-axis **E8.EE15:** Summer/Winter Solstice and Spring/Autumnal Equinox **E8.EE16:** Map projections of major atmospheric and oceanic currents. **E8.EE17:** Graphs of annual average temperatures; distinctions among equatorial and mid-latitude and polar profiles **E8.EE18:** GIS models and representations Exclusions: **E8.EE19:** Precession of axis **E8.EE20:** Coriolis effect	**E12.EE5:** Models, representations, and/or map projections of volcanoes, plate boundaries. **E12.EE6:** GIS visualizations **E12.EE7:** Urban heat islands
Technical Vocabulary	**E4.EE9:** Evaporation, convection cells, light, heat, warm, cold, temperature	**E8.EE21:** Generally limited to vocabulary in content statements with addition of equinoxes, solstices, incoming solar radiation, mean annual temperatures	**E12.EE8:** Generally limited to vocabulary in content statements (see also Tectonics content statements)
Clarification			

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	Grade 4	Grade 8	Grade 12
	Climate and Weather (CW)		
Examples	**E4.CW1:** Functions of simple weather instruments **E4.CW2:** How weather conditions may change during the day, from day to day, and over seasons. Exclusions: **E4.CW3:** Should not assume all students are familiar with four seasons, as many students live in tropical regions and may never have experienced snow	**E8.CW1:** Mechanism of convection cells as a driver of winds: A difference in how water and land absorb energy from the sun results in uneven heating, causing a convection current to develop. We experience moving air at the bottom of this current as wind. (Sea and land breezes can be used as context to assess understanding of forces that drive winds.) **E8.CW2:** Uneven heating causes global wind patterns as air rises over the tropics and falls closer to the poles, forming huge convection (Hadley) cells. **E8.CW3:** Movements of winds across the surface of the globe cause rotating weather systems to develop. These systems can be related to weather maps and storms. **E8.CW4:** Extensive worldwide ocean currents, driven by convection (Conveyor Belt) due to changes in temperature and salinity play an important role in climate. Exclusions: **E8.CW5:** Names of convection processes such as Hadley Cells, Coriolis Effect, or Conveyor Belt theory.	**E12.CW1:** Energy flow from the sun through the atmosphere (provides a context for assessing understanding of both weather and climate). **E12.CW2:** Application of energy transfer concepts to weather and climate phenomena. For example, how local topography affects weather; how greenhouse gases "trap" infrared energy; and how rotation of Earth affects global wind patterns and storm systems (Coriolis Effect). **E12.CW3:** Major weather and climate phenomena can include the jet stream, Hi and Lo pressure areas, phenomena related to weather fronts, and possibly El Niño. Exclusions: **E12.CW4:** Going beyond application of physics principles, i.e., students should not be expected to be meteorologists.
Instruments	**E4.CW4:** Images of or actual weather instruments (thermometers, weather vanes, anemometers, rain gauges)—use of these simple instruments to measure weather conditions Exclusions: **E4.CW5:** Use of barometers to measure pressure or instruments to measure humidity (both are weather conditions that are harder for 4th graders to visualize and experience).	**E8.CW6:** Computer animations illustrate global patterns (animations can be used to stimulate questions). **E8.CW7:** Although not explicitly referenced in the 8th grade content statement, reference can be made to weather instruments, including those for 4th grade, plus barometers to measure pressure.	**E12.CW5:** Data on past climates and levels of greenhouse gases provided by ice cores. **E12.CW6:** Manipulation of computer simulations to demonstrate how physics principles (and especially energy transfer concepts) help to explain global weather phenomena. For example, a simulation might enable students to manipulate factors (such as fossil fuel use) to mitigate future global warming.

	Grade 4	Grade 8	Grade 12
Climate and Weather (CW)			
Representations	**E4.CW6:** Interpretation of bar graphs (histograms), where the x axis is hours or days and the y axis is temperature or rainfall. **E4.CW7:** Illustrations (students can be shown illustrations and asked about different weather conditions over hours, days, or months). Exclusions: **E4.CW8:** How weather differs in different climate zones.	**E8.CW8:** Diagrams of weather systems and/or satellite images of Earth (students can be shown these and asked fundamental questions about storm systems). **E8.CW9:** Interpretation of weather maps, which generally show weather patterns intermediate between global and local scales.	**E12.CW7:** Interpretation of graphs, charts, and maps, both in print and computer displays
Technical Vocabulary	**E4.CW9:** Common vocabulary related to the instruments, weather conditions, and units. For example, thermometer (temperature in °C) rain gauge (amount of rain in centimeters) weather vane (direction from which wind is coming using compass points). Exclusions: **E4.CW10:** Terms related to pressure or humidity or long-term climate trends.	**E8.CW10:** There are a considerable number of terms relevant this subtopic, including various names of weather instruments, conditions, and phenomena (e.g., high and low pressure areas, warm and cold fronts). Use the most common terms. Exclusions: **E8.CW11:** Regarding drivers of weather and its effects, avoid technical terms where possible	**E12.CW8:** Technical terms related to both the physics principles and the weather and climate phenomena are appropriate, although emphasis should be on understanding the processes rather than knowing the names of the processes.
Clarification	**E4.CW11:** Emphasis is on observations and direct measurements of weather conditions locally, and predicting changes in weather over time spans of days, weeks and months. Exclusions: **E4.CW12:** Relating weather to long-term climate changes.	**E8.CW12:** Global weather patterns and how these affect local weather. Exclusions: **E8.CW13:** Quantitative analysis of energy flow through Earth systems.	**E12.CW9:** Application of physics to the understanding of weather and long-term climate changes; and how energy moves through Earth systems.

→ ACTION ITEM: Insert boundaries for biogeochemical cycles.

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