Instructional Focus Documents for Science:

The Disciplinary Core Ideas

Tennessee Department of Education | 2024

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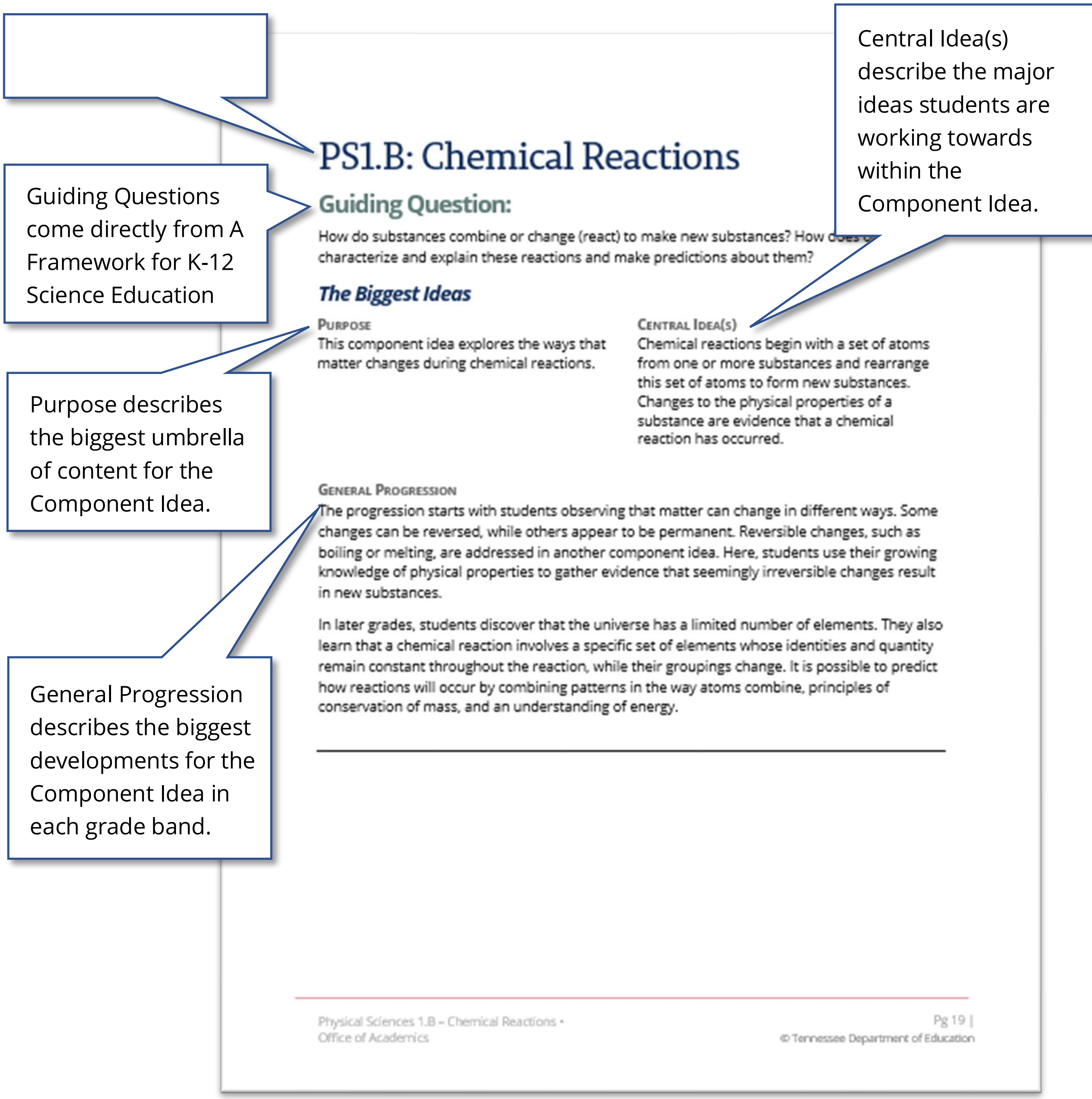
Text Features Guide

Component Idea Cover Page

There are 44 component ideas in the Instructional Focus Documents for Science and each component idea begins with an overview page.



PS1.B: Chemical Reactions

Guiding Question:

How do substances combine or change (react) to make new substances? How does
characterize and explain these reactions and make predictions about them?

The Biggest Ideas

Purpose
This component idea explores the ways that matter changes during chemical reactions.

Central Idea(s)
Chemical reactions begin with a set of atoms from one or more substances and rearrange this set of atoms to form new substances. Changes to the physical properties of a substance are evidence that a chemical reaction has occurred.

General Progression
The progression starts with students observing that matter can change in different ways. Some changes can be reversed, while others appear to be permanent. Reversible changes, such as boiling or melting, are addressed in another component idea. Here, students use their growing knowledge of physical properties to gather evidence that seemingly irreversible changes result in new substances.

In later grades, students discover that the universe has a limited number of elements. They also learn that a chemical reaction involves a specific set of elements whose identities and quantity remain constant throughout the reaction, while their groupings change. It is possible to predict how reactions will occur by combining patterns in the way atoms combine, principles of conservation of mass, and an understanding of energy.

Physical Sciences 1.B – Chemical Reactions • Office of Academics
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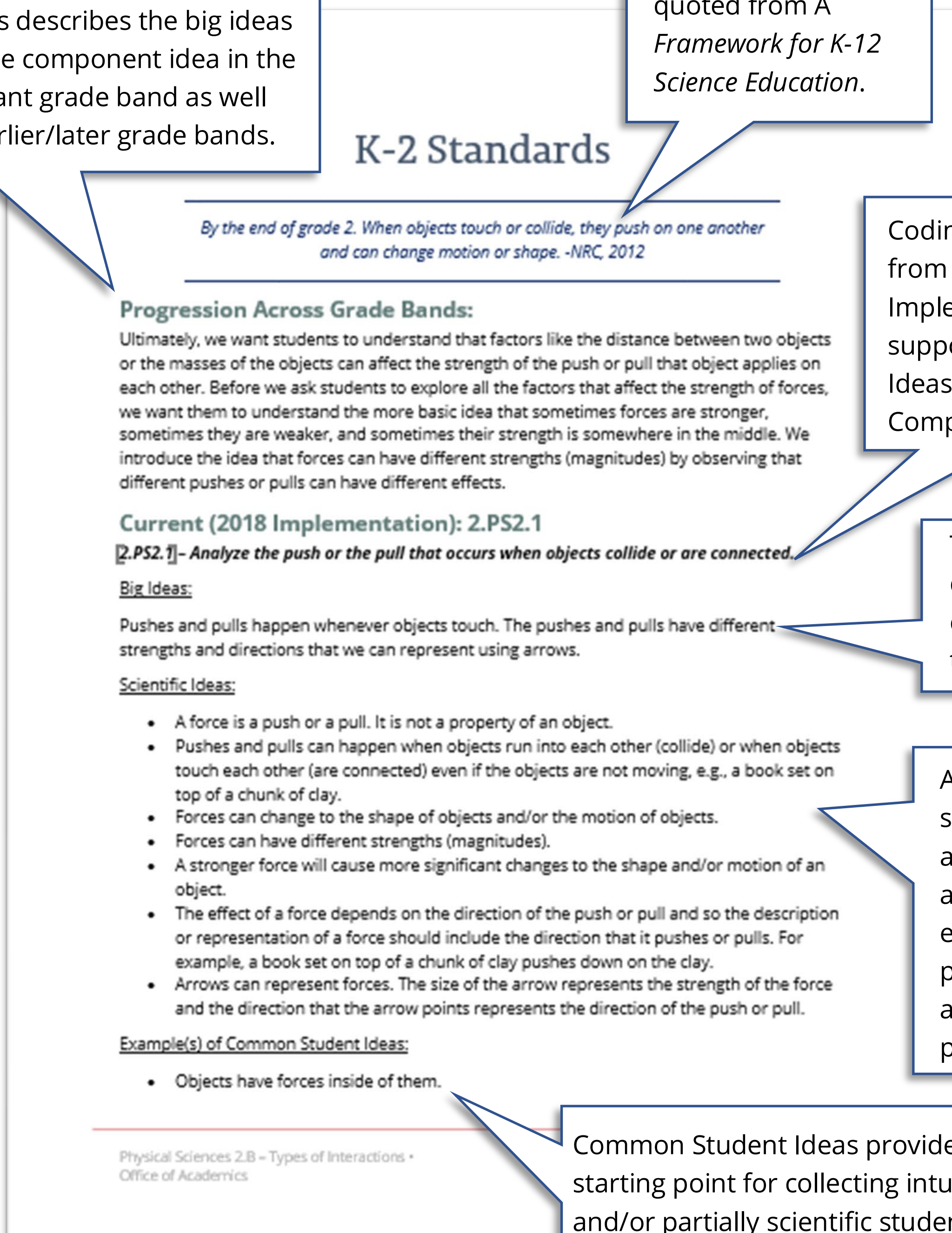
Grade Band Cover Page and Standards Details

Progression Across Grade Bands describes the big ideas for the component idea in the relevant grade band as well as earlier/later grade bands.

Tennessee's science standards align with these end points quoted from A *Framework for K-12 Science Education*.



K-2 Standards

By the end of grade 2. When objects touch or collide, they push on one another and can change motion or shape. -NRC, 2012

Progression Across Grade Bands:

Ultimately, we want students to understand that factors like the distance between two objects or the masses of the objects can affect the strength of the push or pull that object applies on each other. Before we ask students to explore all the factors that affect the strength of forces, we want them to understand the more basic idea that sometimes forces are stronger, sometimes they are weaker, and sometimes their strength is somewhere in the middle. We introduce the idea that forces can have different strengths (magnitudes) by observing that different pushes or pulls can have different effects.

Current (2018 Implementation): 2.PS2.1

2.PS2.1 – Analyze the push or the pull that occurs when objects collide or are connected.

Big Ideas:

Pushes and pulls happen whenever objects touch. The pushes and pulls have different strengths and directions that we can represent using arrows.

Scientific Ideas:

- A force is a push or a pull. It is not a property of an object.
- Pushes and pulls can happen when objects run into each other (collide) or when objects touch each other (are connected) even if the objects are not moving, e.g., a book set on top of a chunk of clay.
- Forces can change to the shape of objects and/or the motion of objects.
- Forces can have different strengths (magnitudes).
- A stronger force will cause more significant changes to the shape and/or motion of an object.
- The effect of a force depends on the direction of the push or pull and so the description or representation of a force should include the direction that it pushes or pulls. For example, a book set on top of a chunk of clay pushes down on the clay.
- Arrows can represent forces. The size of the arrow represents the strength of the force and the direction that the arrow points represents the direction of the push or pull.

Example(s) of Common Student Ideas:

- Objects have forces inside of them.

Physical Sciences 2.B – Types of Interactions •
Office of Academics

Coding and language from the current Implementation that support the Central Ideas for the Component Idea.

The Big Ideas describe the big, conceptual idea for the standard.

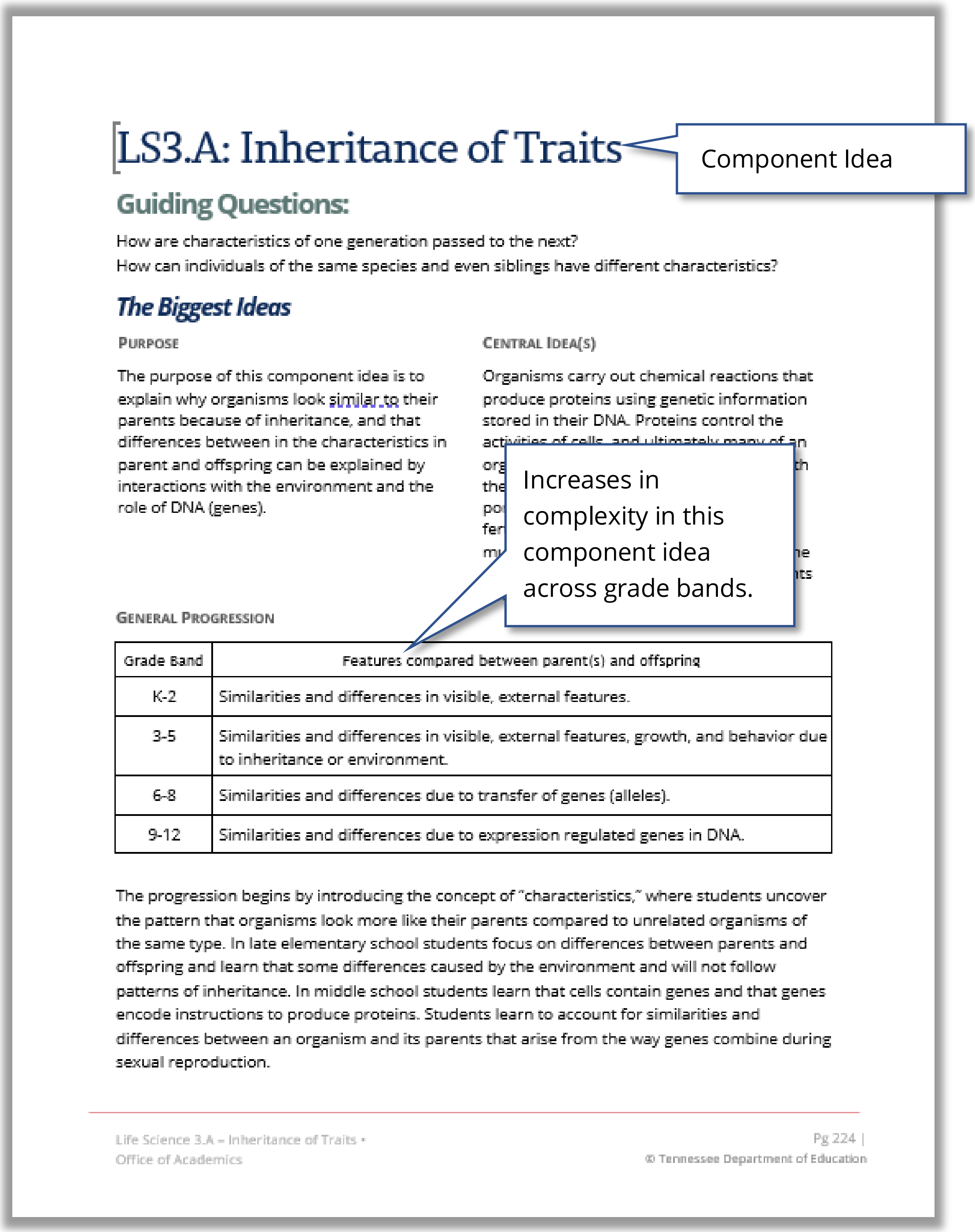
A partial list of scientifically accurate ideas that are useful in explaining natural phenomena and approaching design problems.

Common Student Ideas provides a starting point for collecting intuitive and/or partially scientific student ideas. Educators should note add other ideas they encounter.

Second Edition Updates:

Life Sciences Progressions Table

The cover page for each component idea includes a new table that notes major developments in each grade band.



LS3.A: Inheritance of Traits

Component Idea

Guiding Questions:

How are characteristics of one generation passed to the next?
How can individuals of the same species and even siblings have different characteristics?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to explain why organisms look similar to their parents because of inheritance, and that differences between in the characteristics in parent and offspring can be explained by interactions with the environment and the role of DNA (genes).

CENTRAL IDEA(S)

Organisms carry out chemical reactions that produce proteins using genetic information stored in their DNA. Proteins control the activities of cells, and ultimately many of an org… th the… po… fer… m… ne … nts

Increases in complexity in this component idea across grade bands.

GENERAL PROGRESSION

Grade Band	Features compared between parent(s) and offspring
K-2	Similarities and differences in visible, external features.
3-5	Similarities and differences in visible, external features, growth, and behavior due to inheritance or environment.
6-8	Similarities and differences due to transfer of genes (alleles).
9-12	Similarities and differences due to expression regulated genes in DNA.

The progression begins by introducing the concept of "characteristics," where students uncover the pattern that organisms look more like their parents compared to unrelated organisms of the same type. In late elementary school students focus on differences between parents and offspring and learn that some differences caused by the environment and will not follow patterns of inheritance. In middle school students learn that cells contain genes and that genes encode instructions to produce proteins. Students learn to account for similarities and differences between an organism and its parents that arise from the way genes combine during sexual reproduction.

Life Science 3.A – Inheritance of Traits • Office of Academics

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Biology 1 is now included in the Instructional Focus Documents.

All Life Sciences Component Ideas now cover both K-8 and high school standards. Biology 1 Standards appear across all component ideas within the Life Sciences Disciplinary Core Ideas.

Appendix A include links for individual Biology 1 standards.

Biology 1 Standards Index

(Click on page number to navigate to standard in this document.)

Disciplinary Core Idea	LS1	LS2	LS3	LS4
Biology 1	Bio1.LS1.1 (p. 132) Bio1.LS1.2 (p. 134) Bio1.LS1.3 (p. 147) Bio1.LS1.4 (p. 159) Bio1.LS1.5 (p. 160) Bio1.LS1.6 (p. 162) Bio1.LS1.7 (p. 175)	Bio1.LS2.1 (p. 192) Bio1.LS2.2 (p. 202) Bio1.LS2.3 (p. 215) Bio1.LS2.4 (p. 216) Bio1.LS2.5 (p. 225)	Bio1.LS3.1 (p. 237) Bio1.LS3.2 (p. 238) Bio1.LS3.3 (p. 250) Bio1.LS3.4 (p. 251)	Bio1.LS4.1 (p. 262) Bio1.LS4.2 (p. 273) Bio1.LS4.3 (p. 284) Bio1.LS4.4 (p. 285) Bio1.LS4.5 (p. 295)

Appendix B progressions now include Biology 1 standards.

Discipline: Life Sciences

Disciplinary Core Idea 1: From Molecules to Organisms: Structures and Processes

Component Idea	K–2 Standards (2018)	3–5 Standards (2018)	6–8 Standards (2018)	9-12 Standards (2025)
A. Structure and Function	*K.LS1.2*, 1.LS1.1, 2.LS1.1, *2.LS1.2*	3.LS1.1	7.LS1.1, *7.LS1.2*, 7.LS1.3, 7.LS1.4, 7.LS1.5	Bio1.LS1.1, Bio1.LS1.2
B. Growth and Development of Organisms	1.LS1.2, 2.LS1.3	*No standard*	7.LS1.6, 7.LS1.7, *7.LS1.8*	Bio1.LS1.3
C. Organization for Matter and Energy Flow in Organisms	K.LS1.1	*No standard*	7.LS1.9	Bio1.LS1.4, Bio1.LS1.5, Bio1.LS1.6
D. Information Processing	K.LS1.3, 1.LS1.3	5.LS1.1	*No standard*	Bio1.LS1.7,

PS1.A: Structure and Properties of Matter

Guiding Question:

How do particles combine to form the variety of matter one observes?

The Biggest Ideas

PURPOSE
This strand explores the properties of matter and the atomic theory which explains the behaviors of matter.

CENTRAL IDEA(S)
Matter is made up particles that are too small to see, and nothing else. The smallest of these particles are called atoms. There are a limited number of different types of atoms in the universe. Atoms can combine with other atoms, including atoms of different types. Things like boiling point, solubility, and other physical properties of a substance are caused by the way that particles in that substance interact.

GENERAL PROGRESSION
Our youngest students can observe that there are two very broad categories of materials in the world. We use the words "solid" and "liquid" as names for these materials based on the way they behave. There are phenomena, such as blowing up a balloon, which can only be explained by forces from substances we cannot see. The atomic theory explains these simple observations and more complicated ideas such as the characteristic properties of different types of matter and the conservation of matter.

K-2 Standards

By the end of grade 2. Different kinds of matter exist (e.g., wood, metal, water), and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties (e.g., visual, aural, textural), by its uses, and by whether it occurs naturally or is manufactured. Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces (e.g., blocks, construction sets). Objects or samples of a substance can be weighed, and their size can be described and measured. (Boundary: volume is introduced only for liquid measure.) – NRC, 2012

Progression Across Grade Band

Properties of matter - Students should begin to develop the habit of making careful observations and noticing little details. As they move into higher grades, students learn about new technologies (e.g., thermometers). Each new technology permits new types of observations and new ways to group things. Experiences observing and classifying matter help prepare students for later grades when they explore the structure and organization of the periodic table of elements.

Matter is made of particles - Students learn that all the things around them are different types of matter. We describe substances as solid or liquid depending on the way they behave.

Particles combine in different ways to make different substances - In middle school students will learn that the unimaginably large variety of things in the universe is made up of a relatively small number of different atoms. The seed for this idea begins in early elementary. Students can take apart something and discover that it may be made of only a few different types of pieces. Even so, those same pieces can be reassembled in many ways to make many different, new things.

Current (2018 Implementation): K.PS1.1, K.PS1.2, K.PS1.3

K.PS1.1 – Plan and conduct and investigation to describe and classify different kinds of materials including wood, plastic, metal, cloth, and paper by their observable properties (color, texture, hardness, and flexibility) and whether they are natural or man-made.

Big Ideas:

Learning to make detailed observations allows us to put things into groups. Patterns within and across a group can help us identify other things that a group may have in common.

(Note: Identification of materials based on observable properties exceeds the intent of this standard.)

Scientific Ideas:

- Our senses help us make observations that describe the properties of different materials.
- We can use our observations to put items into groups where each group has some common feature/property. There may be more than one way to group the same set of things.
- It is important to make detailed observations. As our observations become more detailed, we can come up with more possible ways to form our groups.
- Recording the properties of each group helps us add new items to existing groups when the size of the set grows. Sometimes we discover the limitations of our groupings by trying to add a new object to our system of groups and discover that it breaks our pattern.
- We can look for patterns in the properties of materials and their uses to help us select the best material for a task/design (e.g., paper that is soft does better for cleaning up a spill than paper that is smooth).
- Some types of materials exist because of events that happen without humans (e.g., trees can grow on their own to make wood). Other types of materials would not exist if people had not made them.
- People can take materials that are created through natural processes and use them for specific purposes (e.g., wood from trees can be harvested and used to make lumber).
- A material's properties determine how well it will perform at a task (e.g., cloth is not good for cutting paper, but works well to wrap up a group of items).

Example(s) of Common Student Ideas

- Man made materials can be made without things that are found in nature.

K.PS1.2 – Conduct investigations to understand that matter can exist in different states (solid and liquid) and has properties that can be observed and tested.

Big Ideas:

Matter behaves in two general ways. Sometime matter can keep its shape, but other times it is unable to keep its shape and will flow and spread out until its top surface becomes flat.

(Note: Focus on solids and liquids as behaviors of matter, rather than separate states. Students do not yet have the content knowledge to defend that solids and liquids may be the same chemical at different states.)

Scientific Ideas:

- Matter is all the stuff around us – solids and liquids – the things that we can see and/or touch. *(Note: Invisible forms of matter are not appropriate for the K-2 grade band.)*

- Matter can behave in ways that we describe as being either a solid or a liquid. It is possible to pour liquid, but solids keep their shape. *(Note: Focus on large samples of matter. Discussions of particles are not appropriate until grade 3.)*
- Drops of liquids can combine to form a larger drop. Solids or bits of piled up solid do not combine in the same way.
- Liquids can be absorbed, but solids cannot be absorbed.
- Some types of matter on Earth may behave like a solid at one temperature but behave like a liquid at another temperature. For these materials, they will be liquids at lower relative temperatures and solids at higher relative temperatures.
- Matter has weight and sizes that we can measure and compare. (*Note: Size and weights should be compared to other objects, including using tools such as a "rocker" balance/pan balance. Standard units (e.g., metric units) of measure exceed grade level math standards.)*

Example(s) of Common Student Ideas

- When a substance changes states, it has become a new substance.

K.PS1.3 – Construct an evidence-based account of how an object made of a small set of pieces (blocks, snap cubes) can be disassembled and made into a new object.

Big Ideas:

Big things are made up of smaller parts. Using a small variety of parts is small it is still possible to create a wide variety of big things.

(Note: These big ideas intend for students to work with a relatively large number of small pieces but limited to different types of pieces.)

Scientific Ideas:

- Objects can be taken apart and are made of smaller pieces.
- You don't need to have very many different types of pieces to make very different objects, designs, patterns, etc. (e.g., many different patterns can be made with just two colors of blocks).
- Adding or removing pieces makes the object get heavier or lighter, respectively.
- A set of pieces does not get lighter/heavier when it is disassembled and reassembled into something new if all the original pieces are used.

Example(s) of Common Student Ideas

- Changing the shape of an object, without adding or removing pieces, can make the object heavier or lighter.

Revised (2025 Implementation): K.PS1.1, K.PS1.2, K.PS1.3

K.PS1.1 – Plan and conduct an investigation using patterns to classify different kinds of materials by their observable properties (i.e., absorbency, color, texture, hardness, and flexibility), by their uses, and by whether they occur naturally or are manufactured.

K.PS1.2 – Conduct investigations to understand that matter can exist in different states (i.e., solid and liquid) and has properties that can be observed and tested.

K.PS1.3 – Construct an evidence-based account of how an object made of a small set of pieces (e.g., blocks, snap cubes) can be disassembled and made into a new object.

3-5 Standards

By the end of grade 5. Matter of any type can be subdivided into particles that are too small to see, but even then, the matter still exists and can be detected by other means (e.g., by weighing or by its effects on other objects). For example, a model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon; the effects of air on larger particles or objects (e.g., leaves in wind, dust suspended in air); and the appearance of visible scale water droplets in condensation, fog, and, by extension, also in clouds or the contrails of a jet. The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish (e.g., sugar in solution, evaporation in a closed container). Measurements of a variety of properties (e.g., hardness, reflectivity) can be used to identify particular materials. (Boundary: At this grade level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation.) – NRC, 2012

Progression Across Grade Band

(Properties of matter) In early elementary, students learned the importance of making careful and detailed observations. These observations make it possible to group and classify substances. In the 3-5 grade band, students begin to use different technologies (rulers, thermometers, etc.) to make measurements, some of which can now be used to identify new materials.

Matter is made of particles & particles combine to make different substances. In grades K-2, students learned that matter is all the "stuff" around us, and that matter can behave in ways we describe as being a solid or a liquid. Students will now learn that we can explain the behaviors of solids and liquids through a model where all substances are made of particles that are so small that they are not visible. The general term "particle" is used to describe individual units of all different types of matter - atoms, molecules, etc. – regardless of their relative sizes. Students will learn to differentiate between different types of particles in later grades using new observable properties they will encounter in those grades.

Current (2018 Implementation): 3.PS1.1, 3.PS1.3, 5.PS1.1

3.PS1.1 – Describe the properties of solids, liquids, and gases and identify that matter is made up of particles too small to be seen.

<u>Big Ideas:</u>

Matter – all living and non-living things – is made from particles that are too small to be seen. The behavior of solids, liquids, and gases is a result of the motion and arrangement of these invisible particles.

(Note: It is acceptable to discuss individual particles of a substance such as water and student may encounter the chemical formula for water used as shorthand, H_2O. Students are not expected to know that a water particle is made of still smaller atoms/particles of hydrogen and oxygen.)

(Note: The standard addresses the interactions between particles that cause the behavior of solids, liquids, and gases. Transitions between these phases is not part of this standard.)

Scientific Ideas:

- Matter can be broken down into smaller bits. If we continually divide a sample of matter into smaller and smaller bits, it eventually becomes so small that we can no longer see it but continues to exist.
- Eventually the splitting of matter reaches a point where there is only one unit of the substance remaining. This smallest unit of a substance is called a particle.
- Everything that we see around us is made up of an accumulation of these smaller invisible particles. There are different types of materials and objects all around us because there are many different types of particles. Even things that seem small to us (specks of dust or droplets of fog) are made of more particles than we could begin to count.
- The words solid, liquid, and gas describe the way that a substance behaves. All substances are made of groups of invisible particles and the behavior of the substance is caused by the motion and arrangement of the particles.
- Solids resist falling down (i.e., melting/flowing) because the particles all pull on each other. Every particle pulling together prevents particles from changing positions and results in the rigid behavior of solids. *(Note: The pulling between particles is like two magnets pulling together without touching.)*
- Liquids flow but remain a connected substance because the particles can pull on each other enough to remain connected. The flowing behavior of liquids happens because particles hold together, but not enough to keep particles from changing places. The whole substance acts like a group of people dancing and trading partners.
- Particles in a gas cannot pull hard enough on each other and do not connect to each other. Individual particles bounce around in all directions. Matter that behaves like a gas can still push on other objects and we observe this pushing when we exhale or when the wind moves leaves, or as gaseous matter pushes outwards on a balloon to make it larger as it is filled.
- Solids, liquids, and gases can all exist in bits that are too small for us to see or at scales where their bulk behaviors appear to change - e.g., air pollution such as smoke is a very small solid, fog and steam are very small liquid droplets. *(Note: Bulk behaviors or bulk properties refer to behaviors or properties that are observed in a collection of particles but cannot be observed in a single particle.)*

Example(s) of Common Student Ideas

- Matter that has worn away is gone (e.g., As soles of shoes wear away, they are no longer present on Earth).

3.PS1.3 – Describe and compare the physical properties of matter including texture, shape, length, mass, temperature, volume, state, hardness, and flexibility.

Big Ideas:

Observations about matter include measurements of its physical properties. Some of these measurements can be used to identify materials or to determine the suitability of a material for a given purpose.

Scientific Ideas:

- Scientists use different scales of measurement for different properties. Each of these scales is relative to a standardized reference point. E.g., Mass is measured in kilograms which, until recently, was relative to an original “kilogram prototype” – a small cube of platinum. Degrees Celsius is a scale for measuring temperature that is relative to the temperatures where ice forms and where water boils. *(Note: Students are not expected to memorize units of measure or reference points. Students should understand that a reference point is essential for any measuring system.)*
- All types of matter have some properties that can change (e.g., water can have different volumes) but other properties that don’t change - characteristic properties (e.g., hardness).
- It is possible to identify a sample of matter using its characteristic properties.
- Some properties depend on the amount of a substance (e.g., mass and volume) or other conditions (e.g., temperature and shape). Since these properties can change as the amount of a substance changes, it is not possible to identify a sample of matter from these properties alone.

Example(s) of Common Student Ideas

- Any change to a physical property of an object will also change the object’s mass.

5.PS1.1 – Analyze and interpret data from observations and measurements of physical properties of matter to explain phase changes between a solid, liquid, or gas.

Big Ideas:

For each type of matter there are characteristic temperatures where behaviors change between solid/liquid and liquid/gas.

(Note: In middle school students will explain phase changes in terms of the relative motion of particles compared to the strength of the particles’ pull on each other.)

Scientific Ideas:

- Matter is made of particles and these particles can behave as solid, liquid, or gas (see 3.PS3.1).
- For each type of matter, there is a range of temperatures where we will see the sample behave like a liquid. The same type of matter will behave like a solid at any temperature lower than this range and like a gas at temperatures at any temperature above this range.
- The three ranges of temperatures for some substances (e.g., water) are typical temperatures on Earth and therefore we can find examples of these substances behaving as a solid, liquid or gas. For most substances, however, we only can find examples of the substance exhibiting one or two of these types of behaviors.
- If a substance undergoes a phase change and a reversal, its characteristic properties do not change.
- The range of temperatures where a sample behaves as a solid is continuous all the way up until the range of temperatures where a sample behaves as a liquid. The temperature where solid behavior and liquid behavior transition is that substances melting point.
- The melting point of a substance is a characteristic property of that substance.
- The range of temperatures where a sample behaves as a liquid is continuous all the way up until the range of temperatures where a sample behaves as a gas. The temperature where liquid behavior and gaseous behavior transition is that substances boiling point.
- The boiling point of a substance is a characteristic property of that substance.
- Since melting point and boiling point are characteristic properties, they can be used to identify a substance.

Example(s) of Common Student Ideas

- When matter changes states, it becomes a new type of matter.

Revised (2025 Implementation): 3.PS1.1, 3.PS1.3, 5.PS1.1, 5.PS1.2

3.PS1.1 – Develop a model of solids, liquids, and gases to describe that each state of matter is made of particles too small to be seen.

3.PS1.3 – Construct an argument based on evidence that materials have both fixed and changing properties, some of which are useful for identification of a material.

5.PS1.1 – Analyze and interpret data from observations and measurements of the physical properties of matter to explain phase changes between a solid, liquid, or gas.

5.PS1.2 - Analyze and interpret data to show that the amount of matter is conserved even when it changes form, including transitions where matter seems to vanish.

6-8 Standards

All substances are made from some 100 different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Pure substances are made from a single type of atom or molecule; each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with each other; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and vibrate in position but do not change relative locations. Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals). The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. (Boundary: Predictions here are qualitative, not quantitative.) – NRC, 2012

Progression Across Grade Band

Three strands of standards from elementary school are woven together in middle grades – matter is made of particles, particles combine to make different substances, and each different substance has a unique set of observable properties. To explain the behaviors of solids and liquids, students learned that all matter is made of combinations of smaller particles. Students may already be comfortable with the names for some of these invisible particles (e.g., carbon dioxide) however, there has never been an explanation for the unique properties of these or other substances. In middle grades students learn that the variety of types and the characteristic properties of matter can be explained with a limited collection of different atoms that combine to make each different substance. All the behaviors and properties of matter that we can observe are due to the properties of these individual atoms.

Current (2018 Implementation): 7.PS1.1, 7.PS1.2, 7.PS1.3, 7.PS1.6

7.PS1.1 – Develop and use models to illustrate the structure of atoms, including the subatomic particles with their relative positions and charge.

Big Ideas:

A limited number of different types of atoms combine to make all substances in the universe. Every type of atom has a specific number of protons. The number of electrons and neutrons can vary.

Scientific Ideas:

- Matter is anything that has mass and takes up space. Matter continues to exist even when we cannot see it.
- All forms of matter are made of atoms and nothing else. If you remove all the atoms from something, there will be nothing else. There is no other substance holding the atoms.
- There are relatively small number of different types of atoms – around 100.
- The same atoms found on the Earth will be found throughout the universe.
- An atom's type relates directly to its number of protons. E.g., All atoms of carbon will have 6 protons.
- Neutral atoms have equal numbers of protons and electrons. Ions form when atoms gain or lose electrons.
- All an atom's mass is contained in its nucleus – protons and neutrons.
- Atoms of the same type can have different masses. Since each atom's type relates directly to the number of protons, differences in mass are due to different numbers of neutrons.
- The element's atomic mass represents an average mass of a huge number of atoms of that element. Since this is an average, an element's average mass can be seen as the mass of the most common form of the element.
- Elements of one type can become a different type of element by gaining or losing protons.

<u>Example(s) of Common Student Ideas</u>

- Atoms of an element are not made of smaller parts.

7.PS1.2 – Compare and contrast elemental molecules or compound molecules.

<u>Big Ideas:</u>

Elements can combine with one another to produce larger molecules. *(Note: In this standard, the word molecule is used as a general term that does not distinguish between molecular compounds and ionic compounds.)*

<u>Scientific Ideas:</u>

- An atom is the smallest possible unit of a type of matter.
- Compounds form when multiple atoms bind together.
- Elemental molecules consist of two atoms of the same atom.

<u>Example(s) of Common Student Ideas</u>

- Molecules only form when two different types of atoms combine.

7.PS1.3 – Classify matter as pure substances or mixtures based on composition.

Big Ideas:

The characteristic properties of matter are observable in pure substances.

Scientific Ideas:

- An atom is the smallest unit of a substance.
- In a pure substance, all the particles have the same chemical formula.
- A pure substance will have one set of physical properties.
- In a mixture (impure substance) there will be particles with different chemical compositions.
- All particles with the same chemical composition will have the same physical properties, regardless of whether they are present in a pure substance or mixture.
- It is sometimes possible to separate the components of a mixture based on differences in the physical properties of each component.

Example(s) of Common Student Ideas

- When there is more than one type of atom, the sample will always be a mixture.

7.PS1.6 – Create and interpret models of substances whose atoms represent the states of matter with respect to temperature and pressure.

Big Ideas:

A model that includes representations of temperature and pressure explains the unique behaviors of solids, liquids, and gases.

Scientific Ideas:

- Matter is conserved even in transitions where it seems to vanish, such as a liquid becoming a gas.
- All matter is made of particles and nothing more.
- Atoms and molecules in all states are almost always moving, even when the larger object made of these atoms does not appear to be moving.
- Generally, when the particles in a sample of matter are heated, the space between the particles increases.
- Atoms/molecules in a gas are so far apart that they rarely collide. In solids and liquids, the particles are much closer together.
- Particles in a sample are held in proximity to each other by attractions between the particles.
- When a substance is heated, the average speed of the particles increases. As the substance cools, the average speed of the particles decreases.

- Temperature is a measure of the average speed of the particles in a sample of matter.
- Transitions between solids, liquids, and gases are a result of the interactions between individual particles and the motion of those particles. For example, the particles in a liquid are held in proximity to each other by attractive forces until the motion of the particles increases to the point where the forces are no longer strong enough to hold the liquid together.
- Gases exert pressure on a container when they collide with the walls of a container.
- Pressure is a result of the number of particles in a container, the average motion of those particles, and the size of the container.
- It is possible to compress a gas. This decreases the space between the particles and increases the pressure the particles exert on the walls of their container.
- A gas may transition to a liquid or solid as the space between the particles decreases, which can be caused by changes in temperature and/or pressure.

Example(s) of Common Student Ideas

- Pressure describes how hard particles crash into each other.
- Air does not take up space.
- Liquids can be compressed into a smaller volume.
- The pressure of a gas can be directly manipulated.
- Bubbles that form in a boiling liquid are oxygen, carbon dioxide, etc. that were trapped in the liquid.

Revised (2025 Implementation): 7.PS1.1, 7.PS1.3, (overlap with 7.PS1.2)

7.PS1.1 – Evaluate and communicate information that all substances in the universe are made of many different types of atoms that combine in various ways.

7.PS1.3 – Develop a model to explain how changes to a system can be explained by changes in temperature and/or pressure and the effect of those changes on particle motion and/or spatial arrangement.

PS1.B: Chemical Reactions

Guiding Question:

How do substances combine or change (react) to make new substances? How does one characterize and explain these reactions and make predictions about them?

The Biggest Ideas

PURPOSE
This component idea explores the ways that matter changes during chemical reactions.

CENTRAL IDEA(S)
Chemical reactions begin with a set of atoms from one or more substances and rearrange this set of atoms to form new substances. Changes to the physical properties of a substance are evidence that a chemical reaction has occurred.

GENERAL PROGRESSION
The progression starts with students observing that matter can change in different ways. Some changes can be reversed, while others appear to be permanent. Reversible changes, such as boiling or melting, are addressed in another component idea. Here, students use their growing knowledge of physical properties to gather evidence that seemingly irreversible changes result in new substances.

In later grades, students discover that the universe has a limited number of elements. They also learn that a chemical reaction involves a specific set of elements whose identities and quantity remain constant throughout the reaction, while their groupings change. It is possible to predict how reactions will occur by combining patterns in the way atoms combine, principles of conservation of mass, and an understanding of energy.

K-2 Standards

By the end of grade 2. Heating or cooling a substance may cause changes that can be observed. Sometimes these changes are reversible (e.g., melting and freezing), and sometimes they are not (e.g., baking a cake, burning fuel). – NRC, 2012

Progression Across Grade Bands:

As part of component idea PS1.A, students are learning that observable materials behave as either a solid or a liquid. Component idea PS1.B intends for students to encounter a variety of ways that matter can change and that we can observe and describe these changes. For example, some solids may become misshapen if they briefly behave like liquids. It is possible to cause these changes by heating or cooling the material. If we heat/cool the material again, it may be possible to undo the earlier changes. In later grades students encounter more complicated changes like chemical reactions

Temperature is a persistent theme in this progression – temperature is involved in reversible/irreversible changes, temperature as an indicator of the motion of particles influences phase changes and the dissolving materials, and finally that the motion and energy of a particle govern chemical reactions.

Current (2018 Implementation): No Standard - component idea covered in 3.PS1.2

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. When two or more different substances are mixed, a new substance with different properties may be formed; such occurrences depend on the substances and the temperature. No matter what reaction or change in properties occurs, the total weight of the substances does not change. (Boundary: Mass and weight are not distinguished at this grade level.) – NRC, 2012

Progression Across Grade Bands:

The early part of this progression introduces students to the way that materials can change. The earliest examples of changes are those caused by heating and cooling. Students then look at changes that occur when different materials are mixed. As they learn about characteristic properties of matter in PS1.a, students apply this understanding to describe the types of changes they observe.

Current (2018 Implementation): 3.PS1.2, 5.PS1.2, 5.PS1.3, 5.PS1.4

3.PS1.2 – Differentiate between changes caused by heating or cooling that can be reversed and that cannot. *(Aligns to K-2 endpoint for this component idea)*

Big Ideas:

Matter can change. Heating or cooling are two ways that it is possible to cause changes to matter.

Scientific Ideas:

- Matter is all the "stuff" on Earth and in space.
- Solids, liquids, and gases are all ways of describing patterns in the behavior of matter. Each of these phases has observable properties. (For example, solids maintain their shape, even against gravity or other forces that may act on them.)
- All matter is made of tiny, invisible particles. The motion and arrangement of these smaller particles will cause materials to behave as solids, liquids, and gases.
- Substances can undergo different types of changes such as mixing, changing state, dissolving, or being cut or broken into smaller pieces.
- Heating or cooling a substance causes the motion and/or arrangement of the particles to change. During these changes, matter that typically behaves as a solid may become misshapen or matter that behaves as a liquid may exhibit properties of a solid such as maintaining its shape.
- Changes are reversible when only the motion and/or position of the particle's changes.
- The production of light, heat, smoke, color change, or producing an odor are typical evidence that indicate when a change is irreversible.

Example(s) of Common Student Ideas

- Once a solid has turned into a liquid, it cannot become a solid again.

5.PS1.2 – Analyze and interpret data to show that the amount of matter is conserved even when it changes form, including transitions where matter seems to vanish.

Big Ideas:

It is possible to account for all the original matter in a sample even when it seems that matter has disappeared through careful measurements of the total system mass.

(Note: Students are not expected to be able to differentiate between dissolving, vaporizing, and reacting as possible causes for the disappearance of matter.)

Scientific Ideas:

- All substances are made of particles that are so small that they are invisible. *(Note: It is not technically correct for students to refer to the particles as atoms, but students will not learn the distinction until middle school.)*
- All substances can exist as solid, liquid, and gas.
- It is possible for matter to change states in a variety of different ways.
    - Matter can go through phase changes. As a gas, individual particles all move very far away from each other.
    - Some solids will disappear when placed into certain liquids.
    - Matter can react and form new particles that may be gases when they are formed.
- When substances mix, change state, or dissolve, or when objects are cut or broken into smaller pieces, the total mass of all the matter will always remain the same.
- Regardless of the form that the products of these processes may take (for example, when a sugar cube dissolves in water or a chemical reaction produces a gas), the mass will always stay the same.
- If it appears that the mass has changed, it is because some material has not been accounted for.
- Light and heat are not substances (matter), their presence or absence does not affect the mass of the matter.

Example(s) of Common Student Ideas

- In a closed system, mass decreases after a solid dissolves in a liquid
- When humans use different types of fuels for energy, the fuel (matter) just disappears. For example, gasoline is used up in the car and disappears.
- When decomposers break down the remains of living organisms, the mass decreases.
- Matter can disappear with repeated division, dissolving, evaporation, or chemical change.

5.PS1.3 – Design a process to measure how different variables (temperature, particle size, stirring) affect the rate of dissolving solids into liquids.

(Note: The phrase "particle size" in the standard refers to the size of a group of particles (e.g., grains of sugar compared to sugar cubes), not to the size of an individual particle.

Big Ideas:

Dissolving is a process that happens at the scale of individual particles. Factors that change the motion of individual particles and interactions between individual particles will affect how fast something will dissolve.

Scientific Ideas:

- A solid is made of many particles that are joined together to form the larger solid. When a solid dissolves in a liquid, these particles become disconnected and spread out into the liquid. The solid appears to vanish because its individual particles are too small to be seen once they spread out.
- Dissolving occurs at the surface of the solid first.
- Particles in a liquid are moving. When a particle from the liquid collides with a particle that is part of the solid the collision can cause that particle to be pushed away from the other particles that are part of the solid.
- In any substance, the particles move faster and have more energy at higher temperatures than they do at lower temperatures. As a result, it is easier to dissolve materials at higher temperatures because the collision involves more energy.
- At low temperatures, the particles of a liquid move slowly and may not have enough energy to break apart the solid when the particles collide. As a result, it is harder or perhaps not possible to dissolve materials at low temperature.
- Stirring causes the particles in the liquid to move faster – increasing motion energy of the particles. Since the particles in the liquid have more energy, they are more likely to push apart the particles in the solid. As a result, it is easier to dissolve materials by stirring a liquid.
- When a solid substance is split or ground it has more surfaces exposed to the particles in the liquid. This makes it more likely that the particles in the liquid will collide with the particles that are part of the smaller bits of the solid. As a result, it is easier to dissolve materials that are ground into smaller pieces.

Example(s) of Common Student Ideas

- When a substance dissolves in a liquid, it has melted – melting and dissolving are the same process.

5.PS1.4 – Evaluate the results of an experiment to determine whether the mixing of two or more substances results in a change in properties.

Big Ideas:

Mixing chemicals can cause changes to the characteristic properties of a substance. *(Boundary: students are not expected to use the characteristic properties to identify substances.)*

Scientific Ideas:

- In a pure sample of any substance, there are properties that are considered characteristic properties because they do not change regardless of the time, location, size, shape, or amount of the substance.
- Sometimes the mixing of two substances can lead to a change in properties, but other times there are no changes.
- Changes to the characteristic properties within a mixture are evidence that a new substance has formed when two substances were mixed are.
- Changes to properties may occur when the mixing occurs at a higher temperature even when there are not observable changes at a lower temperature.

Example(s) of Common Student Ideas

- A change to any property is evidence that a new substance has formed.

Revised (2025 Implementation): 3.PS1.2, 5.PS1.2, 5.PS1.3

3.PS1.2 – Construct and explanation about the effects of heating and cooling a substance differentiating between changes that can be reversed (i.e., freezing & melting) and those that cannot (e.g., baking a cake or burning fuel).

5.PS1.2 – Analyze and interpret data to show that the amount of matter is conserved even when it changes form, including transitions where matter seems to vanish.

5.PS1.3 – Construct an argument using the physical properties of matter that combining substances may or may not result in a new substance.

6-8 Standards

By the end of grade 8. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. The total number of each type of atom is conserved, and thus the mass does not change. Some chemical reactions release energy, others store energy. – NRC, 2012

Progression Across Grade Bands:

This component idea began by looking at different conditions that could cause matter to change. This included heating and cooling, dissolving, and mixtures. Students observed that conditions that may cause changes in some types of matter may have no impact on other types of matter. Students have learned that substances are made from invisible particles, but prior to middle grades students had not learned that the universe contains a limited number of different types of particles and the different materials we find are all made from this limited set. As part of their exploration of atomic theory, students can use their understanding of the characteristic properties of matter to explain when changes have occurred in the way that a set of atoms are grouped during a chemical reaction.

Current (2018 Implementation): 7.PS1.4, 7.PS1.5

7.PS1.4 – Analyze and interpret chemical reactions to determine if the total number of atoms in the reactants and products support the Law of Conservation of Mass.

Big Ideas:

No amount of matter goes away during chemical reactions.

Scientific Ideas:

- Chemical reactions involve at least two different types of atoms. During a chemical reaction atoms become grouped in new ways.
- The mass of an atom does not change. *(Boundary: Discussions of isotopes exceed the intent of this standard.)*
- The new substances that form during a chemical reaction are made of the same kinds of atoms as the original substances.
- Atoms do not change into a different type of atom during a chemical reaction.
- The total number of each different type of atom will not change after a reaction occurs.
- When substances mix, undergo chemical reactions, change state, or dissolve, or when objects are cut or broken into smaller pieces, the total mass of all the matter will remain the same.

- If it appears that the mass has changed, it is because there is some material that has not been accounted for (e.g., some sugar spilled onto the counter while it was being poured, gas escaped from the sample).

Example(s) of Common Student Ideas

- If a solid forms during a reaction, then the mass will be greater (i.e., a precipitation reaction).
- If a solid dissolves in a liquid, then the mass will decrease.
- When a chemical reaction occurs, such as the burning of gasoline, then the matter just disappears.
- In a chemical reaction, one type of atom transforms into a different type of atom.

7.PS1.5 – Use the periodic table as a model to analyze and interpret evidence relating to physical and chemical properties to identify a sample of matter.

Big Ideas:

Many substances react chemically with other substances to form new substances with different characteristic properties.

Scientific Ideas:

- In a pure sample of any substance, there are properties that are considered characteristic properties because they do not change regardless of the time, location, size, shape, or amount of the substance.
- If two samples have identical characteristic properties, then they are the same substance.
- If there is even one difference in the characteristics of two substances, then they are different substances.
- Characteristic properties should be observed at the same temperature and pressure.
- Characteristic properties for a substance result from the type, number, and arrangement of the atoms in molecules of a substance. Two substances can have the same type and number of atoms, but if they are arranged differently, then the two substances will have different characteristic properties.
- When substances react chemically, one or more new substances is formed.
- If a new substance does not appear, then a chemical reaction did not occur.
- The products of a chemical reaction can be identified as new substances because each product has characteristic properties from the original substances under the same conditions.
- Characteristic properties are the same throughout a sample.

Example(s) of Common Student Ideas

- Chemical reactions cannot be reversed.

Revised (2025 Implementation): 7.PS1.2, 7.PS1.4

7.PS1.2 – Collect and analyze data about the physical properties of the components of a mixture to use as evidence that the identities of the contents change during a chemical reaction.

7.PS1.4 – Use computational thinking to demonstrate that all atoms in the reactants are present in the products of a chemical reaction supporting the Law of Conservation of Mass.

PS1.C: Nuclear Processes

Guiding Question:

Which forces hold nuclei together and mediate nuclear processes?

The Biggest Ideas

PURPOSE

This component idea explains how the different types of atoms can form and how the nucleus of the atom can exist even when it seems that the positive charges in the nucleus of an atom should cause it to blow apart.

CENTRAL IDEA(S)

The nucleus of an atom contains particles with a positive charge. We know that with charged particles "opposites attract, and like charges repel." When charges are close together in the nucleus of the atom, the strong nuclear force is stronger than the electrostatic charge and is able to hold together the positively charged particles in the nucleus.

GENERAL PROGRESSION

In the K-2 and 3-5 grade bands there are no standards within this component idea because the particles discussed in this progression are the tiny particles that make up atoms. There are concepts covered in other component ideas, such as magnets and static electricity, which provide a foundation for understanding how particles in the nucleus of atoms interact. In middle school students learn that there are a limited number of types of atoms in the universe (PS1.A). This component idea explores the forces that hold the nucleus of an atom together. These forces make it possible for smaller elements to combine and make heaver elements. Humans have learned to release and recapture the energy stored in the nucleus of the atom.

K-2 Standards

By the end of grade 2. [Intentionally left blank] – NRC, 2012

Progression Across Grade Bands:

This progression does not have concepts in this grade band. The ideas students are learning about pushes and pulls (PS2. A) are necessary to understand the forces in the nucleus of an atom in later grades.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. [Intentionally left blank] – NRC, 2012

Progression Across Grade Bands:

This progression does introduce concepts in this grade band. However, an understanding of nuclear processes requires students to apply concepts from within this grade band including the ability of forces to act even when objects are not in contact (PS2.B) and the existence of matter in forms that we cannot see directly (PS1.A).

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

6-8 Standards

By the end of grade 8. Nuclear fusion can result in the merging of two nuclei to form a larger one, along with the release of significantly more energy per atom than any chemical process. It occurs only under conditions of extremely high temperature and pressure. Nuclear fusion taking place in the cores of stars provides the energy released (as light) from those stars and produced all of the more massive atoms from primordial hydrogen. Thus, the elements found on Earth and throughout the universe (other than hydrogen and most of helium, which are primordial) were formed in the stars or supernovas by fusion processes.
– NRC, 2012

Progression Across Grade Bands:

Many students are likely to know the expression that "opposites attract" from their investigations with magnets. They may also know that "like charges repel" from explorations with static electricity. These early discussions always related to large, charged objects (e.g., a glass rod rubbed with silk, a balloon or rubber rod rubbed with flannel).

Since this is the students first exposure to atoms, it is not necessary to describe all of the subatomic charged particles – protons, neutrons, and electrons. The middle grades focus of this progression should be on the formation of the nucleus of the atom. Even though electrons are mentioned in the standards, concepts like the formation of ions and bonding do not relate to the nucleus. It is sufficient for students to understand that a pair of nuclei can fuse inside of stars and how this process can explain the origin of other, heavier elements.

As early as kindergarten, students learn that sunlight causes Earth's surfaces to warm (PS3.A). Students learn that warming is caused by energy transfer (PS3.B) and therefore there must be a source for the energy coming from the Sun. Students also learn that each element emits a characteristic wavelength of light (PS4.A). Examining this light reveals that the ratio of hydrogen to helium is lower in older stars compared to younger stars. This happens because atoms of hydrogen fuse to create new atoms of helium. This fusion of two hydrogen nuclei also explains the release of energy from stars.

Students learn that protons give the nucleus its positive charge. The hydrogen nucleus contains only one proton. In high school, students will explain that the collision of two hydrogen nuclei forces two protons to fuse which creates a heavier atom of helium. This conflicts with students' understanding that positive charges should repel each other. The strong nuclear force, caused by neutrons, overcomes the electrostatic force pushing the protons apart.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): 8.PS1.1, 8.PS1.2

8.PS1.1 – Use a model to understand that atoms are a system composed of a positively charged nucleus surrounded by one or more negatively charged particles called electrons.

8.PS1.2 – Develop a model to explain how the light coming from distant stars and the formation of heavier atoms is the result of changes in the composition of the nucleus of the atom and the energy released during the process of nuclear fusion.

PS2.A: Motion and Stability: Forces and Interactions

Guiding Question:

How can one explain and predict interactions between objects and within systems of objects?

The Biggest Ideas

PURPOSE

This purpose of this component idea is for students to learn how to describe motion and to learn when and how forces cause an object's motion to change.

CENTRAL IDEA(S)

We use words, phrases, and measurements to describe how objects move. The same descriptions apply to any sized object – from huge planets to invisible particles. Phrases such as" sitting still" or "constant speed" tell us that the motion of the object is not changing. When we hear these phrases, we know that the forces pushing and pulling on the object are balanced. Other times we describe changing motion including speeding up, slowing down, coming to a stop, starting from a stop, or changing direction. These descriptions tell us that an unbalanced systems of forces are acting on the object.

GENERAL PROGRESSION

This progression begins with students learning to notice and describe how an object is moving, or how a force (push or pull) acts on an object. In later elementary grades students observe that many times an object has more than one thing pushing or pulling on it simultaneously. This observation leads to discussions of multiple forces behaving like a system. Students learn that we can figure out whether a system of forces is balanced or unbalanced by observing an object's motion. In the middle grades students will learn how to evaluate systems of forces to be able to make predictions about how a system of forces will change an object's motion.

K-2 Standards

By the end of grade 2. Objects pull or push each other when they collide or are connected. Pushes and pulls can have different strengths and directions. Pushing or pulling on an object can change the speed or direction of its motion and can start or stop it. An object sliding on a surface or sitting on a slope experiences a pull due to friction on the object due to the surface that opposes the object's motion. – NRC, 2012

Progression Across Grade Bands:

The progression on forces and motion begins with students learning to describe motion and forces. Descriptions of motion and forces have two things in common. Both include a description of the magnitude (How fast is the motion or how strong is the force?) and the direction (Which way is it moving or pushing?). In later grades students begin to consider that one object can experience more than one force at a time. In early elementary students should also begin to describe the cause-and-effect relationship between forces and motion, by observing that forces can cause the motion of objects to change – "When I push on this harder, it moves faster."

Current (2018 Implementation): 2.PS2.2

2.PS2.2 – Analyze the push or pull that occurs when objects collide or are connected.

Big Ideas:

Complete descriptions of forces and motion allow us to see the way that forces cause changes to the motion of objects.

Scientific Ideas:

- Some words can describe how objects appear to move (e.g., fast or slow, or when objects do not appear to be moving, stopped or at rest).
- Some words describe changes to the way an object appears to move (e.g., speeds up, slows down, comes to a stop, starts moving).
- Descriptions of the motion of an object should also describe the direction the object is traveling (e.g., right, up, towards the wall, away from me).
- Pushes and pulls can have different strengths *(Note: Students are not expected to measure the strength of forces. However, students can make relative comparisons of forces, such as stronger, weaker, harder, softer).*
- Stronger pushes/pulls make an object move faster than weaker pushes/pulls.

- When objects run into each other, the motion of the objects will change. Changes to the motion can include speeding up, slowing down, changing direction, starting, stopping, etc.
- If the motion of an object changes, then something must have pushed or pulled on it.
- Friction pushes in the opposite direction that an object is moving.
- Friction causes objects to slow down when they are sliding across a surface and prevents objects from sliding down surfaces.

Example(s) of Common Student Ideas

- A force is something that resides in an object (e.g., “a force of motion”).
- Objects must be able to move on their own to create a force (e.g., tables cannot push or pull).

Revised (2025 Implementation): 2.PS2.1

2.PS2.1 – Analyze the push or the pull that occurs when objects collide or are connected.

3-5 Standards

By the end of grade 5. Each force acts on one particular object and has both a strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. (Boundary: Qualitative and conceptual, but not quantitative addition of forces are used at this level.) The patterns of an object's motion in various situations can be observed and measured; when past motion exhibits a regular pattern, future motion can be predicted from it. (Boundary: Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.)
– NRC, 2012

Progression Across Grade Bands:

In earlier grades students learned ways to describe forces and motion that include the strength and the direction of the forces and the motion. In this grade band, students learn to identify patterns in the motion of an object, such as when an object moves at a constant speed. As students deepen their understanding of forces, they learn that an object can experience more than one force at a time and that the collection of forces acting on an object is a system. In middle school, students learn that a "net force" describes the combination of forces of an unbalanced system. Understanding a net force allows students to quantify and make predictions about how an object's motion may change.

Current (2018 Implementation): 5.PS2.1, 5.PS2.2

5.PS2.1 – Test the effects of balanced and unbalanced forces on the speed and direction of motion of objects.

Big Ideas:

Objects may experience multiple forces acting at once. When the system of forces is balanced the motion of the does not change. Unbalanced forces cause the motion of the object to change.

(Boundary: Students are expected to analyze situations where all of the forces act along the object's line of motion.)

Scientific Ideas:

- The description of a force includes information about the strength of the force and the direction that it pushes or pulls on an object. Arrows can be used to represent force –

the length of the arrow represents its magnitude, and the arrowhead indicates its direction.

- The description of an object's motion includes information about the speed of the object and the direction that it is moving.
- More than one force can push or pull on an object at the same time. Together, all the forces can be described as a system.
- The effects of forces combine when two forces push or pull in the same direction. The effects of forces that push or pull in opposite directions can fully or partially cancel out.
- Two equal forces acting on the same object, in opposite directions cancel each other out. This is one example of a system of balanced forces.
- Systems of balanced forces can cause objects to start moving, stop moving, change speed, or change direction depending on the direction of the forces and the initial motion of the object.
- If an object is at rest and a system of balanced forces act on that object, then the object will stay at rest.
- If an object is already moving and a system of balanced forces acts on that object, then the pattern of the motion of the object does not change.
- An object that is already moving will move faster and faster if there is an unbalanced force acting in the direction of the object's motion.
- An object that is already moving will slow down and then speed up in the opposite direction as long as there is an unbalanced force acting in the opposite direction of the object's motion.
- If the motion of an object is changing, then there are unbalanced forces acting on the object.
- A moving object will keep the same speed and direction of motion unless there is a force acting on it.

<u>Example(s) of Common Student Ideas</u>

- A force is something that resides in an object (e.g., "a force of motion").
- Objects must be able to move on their own to create a force (e.g., tables cannot push or pull).
- Two forces in opposite directions will always cancel each other out, even if the forces are not equal.
- In order to keep moving, an object must always have a force pushing it forward.

5.PS2.2 – Make observations and measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

<u>Big Ideas:</u>

It is possible to measure and describe the motion of an object and use those measurements to make predictions about the future motion or position of an object.

Scientific Ideas:

- Measurements of the motion of an object include a measurement of distance in an interval of time. *(Note: calculations of speed/velocity exceed the expectations of this standard.)*
- Measurements of motion include a direction for the motion. (*Note: In later grades students will use positive and negative values to indicate direction. For example, if +3 means 3 units to the left, then -3 means to the left. In grade 5, it is acceptable to introduce +/- as shorthand for opposite directions, but students are not expected to perform calculations using positive and negative values.*)
- Moving equal distances in equal intervals of time is one pattern of motion students might identify – the object moved 8cm every time the metronome clicked.
- Patterns in the motion of an object can be used to predict and object's position at given time in the future or to determine the amount of time needed for an object to travel some given distance.

Example(s) of Common Student Ideas

- Constant speed is not a pattern in motion.

Revised (2025 Implementation): 5.PS2.1, 5.PS2.2

5.PS2.1 – Plan and carry out an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of the object.

5.PS2.2 – Make observations and measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.

6-8 Standards

By the end of grade 8. For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction (Newton's third law). The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. Forces on an object can also change its shape or orientation. All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. – NRC, 2012

Progression Across Grade Bands:

The two strands of this progression continue from earlier grades – describing motion and describing forces. Building on the 5th grade introduction to systems of forces that act all at once, students now begin to make predictions about the effects of forces on the motion of an object. In earlier grades students could predict whether a system of forces would or would not cause the motion of an object to change. In the middle grades, students learn to make more specific predictions, such as predicting how much the velocity of an object changes if the object experiences a force of a known magnitude and direction. To make these predictions, students must be able to quantify both the forces and motion. All of this depends on being able to set up an inertial frame for a situation.

Current (2018 Implementation): 8.PS2.3, 8.PS2.4, 8.PS2.5

8.PS2.3 – Create a demonstration of an object in motion and describe the position, force, and direction of the object.

(Boundary – students are not expected to differentiate between distance/displacement or speed/velocity.)

Big Ideas:

Defining a coordinate system describing the motion of an object provides a way to make predictions about the motion of an object and the effects of forces on the motion of the object.

Scientific Ideas:

- To measure and make predictions about the motion of an object, there must be a reference point and a coordinate system for a system. There is always more than one possible way to define the system. As long as the coordinate system is used consistently and the reference point does not change, predictions will be the same regardless of the way the system gets defined.

- In a coordinate system, opposite directions will have opposite signs - positive and negative.
- Descriptions of the motion and forces of interacting objects should use the same coordinate system. For example, if moving "to the right" is considered motion in the positive direction, then forces pushing or pulling to the right should also be defined with positive magnitudes.
- The motion of an object can be described by comparing the change in position to the amount of time required for the position to change. Descriptions of an object's motion should include the direction of the motion.
- There are a variety of patterns in the motion of an object including – moving at a remaining at rest, moving at a constant speed, and increasing or decreasing speed at a constant rate. *(Note: Students are not expected to solve algebraic problems relating to time, position, speed, and acceleration, but should be able to identify these events on appropriate representations and make predictions.)*
- Forces can change velocity when the system of forces acting on an object is unbalanced.
- The motion of the object will change based on the sum of the forces acting on the object.
- If the motion of an object is changing, then there is a force acting on an object.

<u>Example(s) of Common Student Ideas</u>

- A constant force is needed to keep an object moving at a constant speed.

8.PS2.4 – Plan and conduct an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

(Boundary: Qualitative evaluation of the effect of unbalanced forces is limited to systems where the forces act along the line of motion of the object in a single dimension. Students may still evaluate how the direction of an object's motion may change when the object experiences net forces perpendicular to its motion.)

(Boundary: Students are not expected to determine resultant forces when a system of forces acts in more than one dimension but may make qualitative predictions about how the motion will change in each dimension independently. E.g., No change to horizontal velocity, but speed up in the vertical direction.)

(Boundary: Students should evaluate systems where individual forces do not change.)

<u>Big Ideas:</u>

When the sum of the forces acting on an object is not zero, there will be a change to either the speed or direction of the object's motion.

<u>Scientific Ideas:</u>

- An object's mass in kilograms is a measurement of the amount of inertia that object contains.
- The motion of an object does not change without the force of pushing or pulling on an object.
- It is harder to change the motion of objects with more inertia. If the same force is applied to objects of different masses, the motion of the object with more mass will change less.
- If multiple forces act simultaneously on an object, the effect of the entire system can be determined by adding up all of the forces that act. *(Boundary: Limited for systems where forces act in line with the object's motion.)*
- Positive and negative values are used to represent forces that act in opposite directions.
- The motion of an object will change according to the sum of the forces it experiences at any given moment.
- If the sum of the forces acting on an object is zero, then the motion of the object will not change. This can include remaining at rest or continuing to move without speeding up or slowing down.
- If an object is moving without a change to either it's speed or direction of motion, then the forces acting on the object are balanced – their sum is zero.

<u>Example(s) of Common Student Ideas</u>

- It will always be harder to change the motion of larger (more volume) objects than it will be to change the motion of smaller (less volume) objects.
- Increasing speed requires increasing force.
- Heavier objects fall faster than lighter objects.
- Objects are hard to move because they exert a force that prevents them from moving.

8.PS2.5 – Evaluate and interpret that for every force exerted on an object there is an equal force exerted in the opposite direction.

<u>Big Ideas:</u>

Forces never exist in isolation. Whenever a force acts on an object, that object will always exert a force of the same type in the opposite direction.

<u>Scientific Ideas:</u>

- Objects that cannot move are still capable of exerting a force.

- There are multiple ways to define a system, but equal and opposite forces only become apparent when a system includes more than one object. (E.g., It is not possible to identify the equal and opposite forces acting on a falling apple, unless the system also includes the Earth. In that case, the equal and opposite forces would be the force of gravity from the Earth pulling on the apple, and the force of gravity from the apple pulling on the Earth.)
- A single pair of equal and opposite forces will only involve two objects in a given system (e.g., during tug of war, one force pair is the force of friction between the puller and the ground and the force of friction between the ground and the puller).
- Equal and opposite forces will always be the same type of force (e.g., friction, tension, gravity).
- The changes in motion caused by a force may not be apparent when one of the objects has substantially more mass than the other object in the system. For example, the Sun and Earth exert gravitational pulls on each other, but the effects of the Earth's gravitational pull on the Sun are not observable because the Sun is so large compared to the Earth.

Example(s) of Common Student Ideas

- During Tug of war, the equal and opposite force pair is the tension force applied by the opposite team and the friction force keeping a player from sliding. (*Note: this is inaccurate because there are more than two objects, and the forces are of different types.*)
- The equal and opposite forces acting on a person sitting in a chair are the weight of the person pushing down and the [normal] force of the chair pushing upwards on the person.

Revised (2025 Implementation): 8.PS2.4, 8.PS2.5, 8.PS2.6

8.PS2.4 – Construct an explanation to describe why the position and motion of object(s) in a system, and the effects of forces on those objects, vary with respect to the observer.

8.PS2.5 – Plan and conduct an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

8.PS2.6 – Evaluate and interpret that for every force exerted on an object there is an equal force exerted in the opposite direction.

PS2.B: Types of Interactions

Guiding Question:

What underlying forces explain the variety of interactions observed?

The Biggest Ideas

PURPOSE

This component introduces students to the different types of forces in the universe that govern how objects in the universe move.

CENTRAL IDEA(S)

There are a variety of named forces in the universe– force of gravity, friction force, normal force as well as informal words, such as “applied force” that we use as placeholders while we learn to define forces. When we look at how forces work at the microscale, our list shrinks to just four forces in the universe. These four forces are gravity, electromagnetism, and the strong and weak nuclear forces. All of the other forces we name are variations of these four forces. The PS2.b progression of standards reveals the nature of forces and effects of forces including the factors that influence their magnitude, direction, and the scales at which each force dominates.

GENERAL PROGRESSION

This progression begins by looking at the effects of forces on objects – to change the motion or shape of an object. In late elementary school students begin to recognize forces in a system and that there are some forces that only exist when objects touch (e.g., friction) and other forces that exist regardless of whether or not objects are touching (e.g., magnetism). By middle school, students conduct investigations that help them determine factors that have an effect on the strength of each different type of forces.

K-2 Standards

By the end of grade 2. When objects touch or collide, they push on one another and can change motion or shape. -NRC, 2012

Progression Across Grade Bands:

Ultimately, we want students to understand that factors like the distance between two objects or the masses of the objects can affect the strength of the push or pull that object applies on each other. Before we ask students to explore all the factors that affect the strength of forces, we want them to understand the more basic idea that sometimes forces are stronger, sometimes they are weaker, and sometimes their strength is somewhere in the middle. We introduce the idea that forces can have different strengths (magnitudes) by observing that different pushes or pulls can have different effects.

Current (2018 Implementation): 2.PS2.1

2.PS2.1 – Analyze the push or the pull that occurs when objects collide or are connected.

Big Ideas:

Pushes and pulls happen whenever objects touch. The pushes and pulls have different strengths and directions that we can represent using arrows.

Scientific Ideas:

- A force is a push or a pull. It is not a property of an object.
- Pushes and pulls can happen when objects run into each other (collide) or when objects touch each other (are connected) even if the objects are not moving, e.g., a book set on top of a chunk of clay.
- Forces can change to the shape of objects and/or the motion of objects.
- Forces can have different strengths (magnitudes).
- A stronger force will cause more significant changes to the shape and/or motion of an object.
- The effect of a force depends on the direction of the push or pull and so the description or representation of a force should include the direction that it pushes or pulls. For example, a book set on top of a chunk of clay pushes down on the clay.
- Arrows can represent forces. The size of the arrow represents the strength of the force and the direction that the arrow points represents the direction of the push or pull.

Example(s) of Common Student Ideas:

- Objects have forces inside of them.

Revised (2025 Implementation): Overlap with 2.PS2.1

2.PS2.1 – Analyze the push or the pull that occurs when objects collide or are connected.

3-5 Standards

By the end of grade 5. Objects in contact exert forces on each other (friction, elastic pushes and pulls). Electric, magnetic, and gravitational forces between a pair of objects do not require that the objects be in contact—for example, magnets push or pull at a distance. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other. The gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center. – NRC, 2012

Progression Across Grade Bands:

In earlier grades students learned that forces have different strengths and that the effect of a force depends on its strength and the directions that it pushes or pulls when objects touch. Now, their ability to describe forces develops further as they learn that there are different types of forces and that some types of forces can affect the shape or motion of objects even if the objects don't ever touch. In later grades, students will consolidate all forces into one of four different types and learn the different factors that influence the strength of each type of force. For now, students will discuss some forces with familiar names such as gravity, friction and magnetic. They also uncover the need to name some less familiar forces such as tension and normal force in order to describe many why some objects move or remain at rest.

Current (2018 Implementation): 3.PS2.1, 3.PS2.2, 5.PS2.3, 5.PS2.4

3.PS2.1 – Explain the cause-and-effect relationship of magnets.

Big Ideas:

Magnetism is one type of force, and the effects of magnets can be seen even if the magnets do not touch. Like other forces, magnetic forces can have different strengths and act in different directions.

Scientific Ideas:

- Magnets have two poles, and we use the names North (N) and South (S).
- Magnetic forces are directional. When two magnets interact, they each experience forces that will either attract or repel them depending on the orientation of the poles of the magnets.
    - When two similar poles (north-north, or south-south) come together, they experience forces that push a pair of magnets away from each other.
    - When two different poles (e.g., north or south) come together, they experience a force that pulls a pair of magnets towards each other.

- The effects of magnetic forces are apparent even if two magnets do not touch each other.
- The strength of the push or pull on a magnet depends on how far it is from another magnet. When two magnets are close together, they experience pushes or pulls that are stronger than when they are further apart.

Example(s) of Common Student Ideas:

- All metals are magnetic.
- Magnets only push/pull on each other when they are touching.
- Magnetic poles are always at the ends of a magnet.
- Magnetism (magnetic fields) only works through air, but not other materials like wood or water.
- Larger magnets are always more powerful than smaller magnets.
- Magnetic fields lines are really there. (Confusing the representation of the field by drawing lines with the actual things.)

3.PS2.2 – Solve a problem by applying the use of the interactions between two magnets.

Big Ideas:

The content from 3.PS2.1 and 3.PS2.2 are the same. This standard is written as a performance expectation that describes a way that students can apply scientific ideas.

Scientific Ideas:

- Magnets have two poles, and we use the names North (N) and South (S).
- Magnetic forces are directional. When two magnets interact, they each experience forces that will either attract or repel them depending on the orientation of the poles of the magnets.
    - When two similar poles (e.g., north-north or south-south) come together, they experience forces that push a pair of magnets away from each other.
    - When two different poles (e.g., north or south) come together, they experience a force that pulls a pair of magnets towards each other.
- The effects of magnetic forces are apparent even if two magnets do not touch each other.
- The strength of the push or pull on a magnet depends on how far it is from another magnet. When two magnets are close together, they experience pushes or pulls that are stronger than when they are further apart.

Example(s) of Common Student Ideas:

- All metals are magnetic.
- Magnets only push/pull on each other when they are touching.

5.PS2.3 – Use evidence to support that the gravitational force exerted by Earth on objects is directed toward Earth's center.

Big Ideas:

Gravity is a type of force the direct of this force always pulls objects together.

Scientific Ideas:

- Force is a pushes or pulls on objects. Forces can have different strengths.
- Forces can cause changes in the shape or motion of an object.
- The effects of forces are observable even when two objects do not touch.
- Gravity is always an attractive force.
- The absolute direction of gravitational forces depends on the positions of two masses. The relative direction of gravitational forces will always push or pull objects towards each other.

Example(s) of Common Student Ideas:

- The Earth must be flat since no one is falling off of the Earth.

5.PS2.4 – Explain the cause-and-effect relationship between two factors (mass and distance) that affect gravity.

Big Ideas:

Gravity, like other forces, can exert varying strengths depending on the mass of the objects involved and the distance between the centers of the two objects.

Scientific Ideas:

- Gravity is a force that interacts between two objects, not a property of either object.
- The gravitational force between two objects pulls them together and has the same strength (e.g., The force pulling the Earth towards the Sun is the same strength as the force pulling the Sun towards the Earth.)
- The force of gravity exists between two objects even when the two objects are not touching.
- As two objects move closer together, the strength of the gravitational force increases.
- The gravitational force pulling two massive objects together is greater than the gravitational force pulling two less massive objects together.

Example(s) of Common Student Ideas:

- The Earth pulls objects towards its center, but the objects do not also pull back on the Earth.

- The force that pulls the Earth towards the Sun is stronger than the force that pulls the Sun towards Earth.
- As long as there is nothing to keep an object from falling, things fall naturally, and there is no force involved.
- Gravity is stronger when you're higher up because things that are dropped from greater heights suffer greater damage and/or are moving faster when they hit the floor.

Revised (2025 Implementation): 3.PS2.1, 5.PS2.3

3.PS2.1 – Explain cause and effect relationships of forces that cannot be seen including interactions between two objects not in contact with each other (i.e., static electricity, magnetism and gravity).

5.PS2.3 – Use evidence to support that the gravitational force exerted by Earth on objects is directed toward the Earth's center.

6-8 Standards

By the end of grade 8. Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—for example, Earth and the sun. Long-range gravitational interactions govern the evolution and maintenance of large-scale systems in space, such as galaxies or the solar system, and determine the patterns of motion within those structures.

Forces that act at a distance (gravitational, electric, and magnetic) can be explained by force fields that extend through space and can be mapped by their effect on a test object (a ball, a charged object, or a magnet, respectively).
– NRC, 2012

Progression Across Grade Bands:

This progression begins by introducing force as pushes or pulls that can have different strengths and can act in different directions. Later in elementary school, students learn to classify forces into different types and explore factors that influence the strength and direction of some of these types of forces. Middle school begins to narrow the number of types of forces by leading students to observe the connection between electricity and magnetism and the factors that influence the nature of these forces.

Current (2018 Implementation): 8.PS2.1, 8.PS2.2

8.PS2.1 – Design and conduct investigations depicting the relationship between magnetism and electricity in electromagnets, generators, and electrical motors, emphasizing the factors that increase or diminish the electric current and the magnetic field strength.

Big Ideas:

Electromagnetic fields can exert forces and the strength of these forces is determined by factors in the design of the devices.

Scientific Ideas:

- Magnetic forces are directional. When two magnets interact, they each experience forces that will either attract or repel them depending on the orientation of the poles of the magnets.

    - When two similar poles (north-north, or south-south) come together, they experience forces that push a pair of magnets away from each other.
    - When two different poles (e.g., north-south) come together, they experience a force that pulls a pair of magnets towards each other.
- Electric currents exist when charged particles flow through a conductor. The current can flow in one of two directions through the conductor.
- Electric currents will create magnetic fields. The properties of these magnetic fields are determined by the electric device (e.g., electromagnet, electric motor)
- Moving a conductor through a magnetic field will cause a current to flow through the conductor. The properties of the current (strength and direction) are a result of elements of the magnetic field and motion of the conductor.

Example(s) of Common Student Ideas:

- Electromagnets are magnetic even when they are switched off.

8.PS2.2 – Conduct and investigation to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Big Ideas:

Non-contact forces can be explained by fields that extend through space and can be mapped by using test objects.

Scientific Ideas:

- A test object is an object that can lead to observations about properties of a field.
- Test objects must be able to interact with the field being studied.
- Test objects will experience a force when placed into a field.
- Field lines represent magnetic fields in space.
- The distance between field lines indicates the strength of the field in space. Lines drawn closer together represent positions in space where the field is stronger.
- The magnitude and direction of the force exerted on the test object is affected by properties (e.g., charge, mass, polarity) of the test object.

Example(s) of Common Student Ideas:

- Objects can only push or pull on each other when they are touching.
- The Earth pulls objects towards its center, but the objects do not also pull back on the Earth.
- The force that pulls the Earth towards the Sun is stronger than the force that pulls the Sun towards Earth.
- As long as there is nothing to keep an object from falling, things fall naturally, and there is no force involved.

- Gravity is stronger when you're higher up because things that are dropped from greater heights suffer greater damage and/or are moving faster when they hit the floor.
- All metals are magnetic.
- Magnets only push/pull on each other when they are touching.
- Magnetic poles are always at the ends of a magnet.
- Magnetism (magnetic fields) only works through air, but not other materials like wood or water.
- Larger magnets are always more powerful than smaller magnets.
- Magnetic fields lines are really there. (Confusing the representation of the field by drawing lines with the actual things.

Revised (2025 Implementation): 8.PS2.1, 8.PS2.2, 8.PS2.3

8.PS2.1 – Conduct an investigation to provide evidence that the size of force fields (electric and magnetic) depends on the magnitudes of the charges, current, or magnetic strengths involved and the distances between interacting objects.

8.PS2.2 – Ask scientific questions about data to determine how manipulating variables can increase or diminish the electric current and magnetic field strength in electromagnets, generators, and electric motors.

8.PS2.3 – Construct an argument using evidence to support the claim that gravitational interactions in a large-scale system (e.g., galaxies and solar system) are attractive and depend on the masses of and distance between interacting objects.

PS2.C: Stability and Instability in Physical Systems

Guiding Question:

Why are some physical systems more stable than others?

The Biggest Ideas

PURPOSE

This component idea helps students learn to evaluate a group of interactions and figure out how these interactions may cause a system to change as well as how a system is able to remain unchanged even in the presence of external influences and changing conditions.

CENTRAL IDEA(S)

Stability can be thought of as the steadiness of a system. A short stack of blocks is more stable than a tall stack of blocks. Stable systems are not as likely to change from external interactions – pushing on the tall stack of blocks is more likely to topple it. Large scale stability (e.g., water level at a dam, or Earth's orbital period) are maintained by interactions at smaller scales (e.g., water flowing in and out of the dammed area, the forces of gravity between the Earth and Sun). Feedback mechanisms that maintain stability as long as systems are within a certain range of conditions.

GENERAL PROGRESSION

Students begin this progression by looking at the way that groups of pushes and pulls interact to keep an object from moving and the way that changes to this group of pushes and pulls may lead to motion. In a sense, the late elementary theme is that "things aren't always what they seem." Sometimes systems are moving, but we can find patterns in their motion (e.g., orbits) and other times things appear not to be changing, but that is because inputs and outputs are balanced (e.g., water behind a dam). Stability and feedback mechanisms are formally introduced in middle school.

K-2 Standards

By the end of grade 2. Whether an object stays still or moves often depends on the effects of multiple pushes and pulls on it (e.g., multiple players trying to pull an object in different directions). It is useful to investigate what pushes and pulls keep something in place (e.g., a ball on a slope, a ladder leaning on a wall) as well as what makes something change or move. – NRC, 2012

Progression Across Grade Bands:

Discussions of stability and instability begin by examining a pair of conditions: being at rest or moving. Students should consider that even objects that are at rest may still be experiencing forces, and that the combination of forces is preventing the object from moving. Things like a door held open by a doorstop or a suction spring toy are good to investigate. Students can create labeled drawings to communicate their ideas about the changes that must occur for these systems to begin moving. This allows students to observe that the system will begin to move when one force is removed.

Current (2018 Implementation): 2.PS2.3

2.PS2.3 – Recognize the effect of multiple pushes and pulls on an object's movement or non-movement.

Big Ideas:

Whether or not an object begins to move, remains at rest, moves at a constant speed, speeds up, slows down, or changes directions depends on the collection of pushes and pulls that an object experiences.

(Note: Advanced terms like net force or balanced and unbalanced forces do not align with the intent of this standard.)

Scientific Ideas:

- A force is a push or a pull.
- Pushes and pulls can cause changes to the motion of an object.
- An object can have more than one thing pushing or pulling on it at once.
- Combinations of pushes and pulls can keep objects from moving.
- Objects that experience only one push or pull begin to move.
- The size of the forces pushing or pulling on an object is important, such as a stronger push or pull will cause an object to move when it is opposed by a weaker push or pull.

Example(s) of Common Student Ideas:

- If an object is moving, then some force is pushing on the object which keeps it moving.

Revised (2025 Implementation): Overlap with 2.PS2.2

2.PS2.2 – Plan and carry out an investigation to demonstrate how pushing and/or pulling an object affects the motion of the object within a system.

3-5 Standards

By the end of grade 5. A system can change as it moves in one direction (e.g., a ball rolling down a hill), shifts back and forth (e.g., a swinging pendulum), or goes through cyclical patterns (e.g., day and night). Examining how the forces on and within the system change as it moves can help to explain the system's patterns of change.

A system can appear to be unchanging when processes within the system are occurring at opposite but equal rates (e.g., water behind a dam is at a constant height because water is flowing in at the same rate that water is flowing out). Changes can happen very quickly or very slowly and are sometimes hard to see (e.g., plant growth). Conditions and properties of the objects within a system affect how fast or slowly a process occurs (e.g., heat conduction rates). – NRC, 2012

Progression Across Grade Bands:

Students have learned that the motion or lack of motion of an object is a result of interactions between groups of pushes and pulls, such as a closely matched game of tug-of-war. Sometimes we may see that an object is moving and after closer examination we may uncover that the forces acting on the object create a pattern in the object's motion – pendulums, orbiting bodies, moving with a constant speed. Students should also come to understand that sometimes objects do not appear to be moving at one level, but that is a result of a balance on input and outputs – a constant water level at a dammed lake is a balance of water flowing in and water released. The topic of stability is formally uncovered in middle school, along with the idea of feedback mechanisms that help to keep a system within a certain range of stability.

Current (2018 Implementation): 5.PS2.5

5.PS2.5 – Explain how forces can create patterns within a system (moving in one direction, shifting back and forth, or moving in cycles), and describe conditions that affect how fast or slowly these patterns occur.

<u>Big Ideas:</u>

Systems can change in a variety of ways. When there is a pattern to the way that motion in a system changes, there will also be a pattern to the underlying forces that cause the motion.

<u>Scientific Ideas:</u>

- A system is a group of objects that interact. For example, objects that push and pull on each other are part of the system. For a child on a swing, the system might include the child, the earth, and the seat of the swing.

- The boundaries of a system might change depending on what aspects of the system are being investigated. For the above system, the chain supporting the seat to the swing may be important to understanding the forces on the seat, but not important to understanding the forces on the person sitting in the seat.
- Systems that contain moving objects may still be stable when there is a pattern to the motion of the objects in the system.
- Looking at a system at different scales may impact whether the system is viewed as changing or unchanging. (examples below)
    - A ball rolling down a hill may appear to be unchanging because the ball continually rolls down the hill, however measurements of the ball's speed reveal that the motion changes as the ball continues to speed up. Examining further, students may see stability in the constant rate of change in the object's motion.
    - The position of a student on a swing changes as they swing back and forth, but measuring the time required to complete one cycle reveals that the amount of time does not change.
    - The position of a planet in its orbit changes throughout the year, however the amount of time needed to complete its cycle and after a certain amount of time (1 year for Earth) the object will return to a prior position.
- Forces can cause changes to the motion of an object.
- More than one force can act on an object at once.
- When there is a pattern in the motion of an object, there will also be a pattern in the underlying forces causing the motion of the object to change.
- Some patterns in motion can be explained by considering the initial motion of an object along with forces acting on the moving object (e.g., a planet's orbit is a result of one force (gravity) acting on an object that is already in motion).

<u>Example(s) of Common Student Ideas:</u>

- Constant speed is not a pattern.
- There are only patterns in an object's motion when it is swinging back and forth.

Revised (2025 Implementation): 5.PS2.4

5.PS2.4 – Explain how forces can create patterns within a system (moving in one direction, shifting back and forth, or moving in cycles), and describe conditions that affect how fast or slowly these patterns occur.

6-8 Standards

By the end of grade 8. A stable system is one in which any small change results in forces that return the system to its prior state (e.g., a weight hanging from a string). A system can be static but unstable (e.g., a pencil standing on end). A system can be changing but have a stable repeating cycle of changes; such observed regular patterns allow predictions about the system's future (e.g., Earth orbiting the sun). Many systems, both natural and engineered, rely on feedback mechanisms to maintain stability, but they can function only within a limited range of conditions. With no energy inputs, a system starting out in an unstable state will continue to change until it reaches a stable configuration (e.g., sand in an hourglass). – NRC, 2012

Progression Across Grade Bands:

Students began this progression with simple interactions of pushes and pulls that kept a system from moving or caused motion in the system. Later in elementary school students developed a more complex understanding of change. Students came to see that motion and change are not necessarily the same thing. In planetary orbits, for example, the planets may be moving, but the pattern in their motions are constant. Or with dams, water may be flowing into or out of the dam, but when these rates are equal, the water level remains unchanged.

In the middle grades, students should come to understand that change and stability are two different ideas. A system may not be moving, but this does not mean the system is stable. Students may have experienced this with a poorly designed chair. Students can explore how feedback mechanisms help maintain stable conditions. Thermostats use feedback mechanisms to help keep temperatures in a comfortable range by controlling heat and air systems in response to temperature changes.

Current (2018 Implementation): No Standard

In the current implementation, there is no standard written for this component idea.

Revised (2025 Implementation): No Standard

PS3.A: Definitions of Energy

Guiding Question:

What is energy?

The Biggest Ideas

Purpose

This component idea describes the different types of energy as well as the properties of systems associated with each type of energy.

Central Idea(s)

Energy is not a real substance – in the same sense that "information" is not a real, tangible substance. Energy is a conceptual tool. There are different types of energy and the amount of each type of energy in a system depends on the properties of the system. It is possible for energy to transfer in or out of a system. This is similar to the way that it is possible to put money in or take money out of a bank. Just as it is possible to move money from one account to another once it has been deposited, it is possible for energy to transform from one type to another within a system.

General Progression

This progression does not begin until late elementary school. However, being able to observe and describe motion (PS2.A) are relevant skills from the K-2 grade band that will be helpful. Students begin this progression with the concept that moving objects possess energy and faster moving objects possess greater amounts of energy. In middle school students will learn that there are a variety of different types of energy and that each different type of energy is associated with certain properties of a system. For example, students will learn that the potential (stored) gravitational energy of a system relates directly to the mass of the object and the height of the object.

K-2 Standards

By the end of grade 2: [Intentionally left blank] – NRC, 2012

Progression Across Grade Bands:

Since energy is an abstract concept, not a physical thing that students can observe, there are no standards about the types of energy in early elementary. There are skills from other component ideas in this grade band, such as observing and describing motion (PS2.A) that are important to this progression in later grades.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. The faster a given object is moving, the more energy it possesses. Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (Boundary: At this grade level, no attempt is made to give a precise or complete definition of energy.) – NRC, 2012

Progression Across Grade Bands:

This component idea introduces students to the different types of energy that we can describe in the universe. The first type of energy students learn about is motion energy, which they will eventually call kinetic energy. A challenge for students in any grade is remembering that energy is not a thing or a substance, it is a concept. In our everyday talk we say things like, "Those orange slices gave me so much energy," or, "If you take a nap, you'll have more energy." These everyday discussions of energy lead students to believe that energy might be a physical substance that builds up inside of them.

It is helpful for students to begin to associate energy with the change in a system. In all cases, if a system changes it is because of an energy change in the system. Students are not expected to relate changes in a system with specific types of energy beyond those specifically named in standards. Even then, treating potential energy as "stored energy" may reduce some common misconceptions about potential energy.

In later grades students will learn to describe all different types of energy and account for events in their lives and the broader universe through energy transfers.

Current (2018 Implementation): 4.PS3.1

4.PS3.1 – Use evidence to explain the cause-and-effect relationship between the speed of an object and the energy of an object.

Big Ideas:

Moving objects possess motion energy. As the speed of an object increases its motion energy increases.

Scientific Ideas:

- Moving objects possess a type of energy called motion energy. *(Note: In later grades, students will use the more technical term, kinetic energy.)*
- Objects that are sitting still do not have motion energy.
- Objects can only gain motion energy when something pushes or pulls on them. Objects at rest cannot start moving without something pushing or pulling on them, and objects

that are already moving will not speed up or slow down unless they push/pull or are pushed/pulled upon.

- The motion energy of an object does not change unless it pushes or pulls on something.
- The faster an object moves, the more motion energy it possesses.
- The motion energy of objects can change as a result of the push or pull that occurs during a collision, one object can speed up (its motion energy increases) and the other object slows down (its motion energy decreases).
- Objects that make more noise tend to slow down (decrease motion energy) faster than objects that move silently.

Example(s) of Common Student Ideas:

- Objects can change their motion energy without a force acting upon them.

Revised (2025 Implementation): 4.PS3.1

4.PS3.1 – Use evidence to explain the cause-and-effect relationship between the speed of an object and the energy of an object.

6-8 Standards

By the end of grade 8. Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. A system of objects may also contain stored (potential) energy, depending on their relative positions. For example, energy is stored—in gravitational interaction with Earth—when an object is raised, and energy is released when the object falls or is lowered. Energy is also stored in the electric fields between charged particles and the magnetic fields between magnets, and it changes when these objects are moved relative to one another. Stored energy is decreased in some chemical reactions and increased in others.

The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and energy transfers by convection, conduction, and radiation (particularly infrared and light). In science, heat is used only for this second meaning; it refers to energy transferred when two objects or systems are at different temperatures. Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. – NRC, 2012

Progression Across Grade Bands:

Students have been introduced to the idea of energy by looking at moving objects and the events that happen when objects collide. There is a general idea that energy can move between objects because objects can start and stop moving. However, students are still likely to treat energy as a substance that is passed between objects. In the middle grades students look at a variety of different circumstances where systems change and learn to describe all of the different types of energy in a system. As they learn to describe the types of energy, they are able to more fully account for all of the transfers needed to support the idea that energy is conserved.

Current (2018 Implementation): 6.PS3.1, 6.PS3.3, 6.PS3.4

6.PS3.1 – Analyze the properties and compare sources of kinetic, elastic potential, gravitational potential, electric potential, chemical, and thermal energy.

<u>Big Ideas:</u>

Studying the arrangement and properties of parts of a system makes it possible to describe the type of energy in the system. Understanding how the types of energy have changed before and after an event makes it possible to observe the conservation of energy.

Scientific Ideas:

- In a system, energy can exist in different forms.
- When a system changes, the types and/or amounts of each type of energy in the system will change in some ways.
- The type of energy associated with moving objects is known as kinetic energy. *(Note: prior to this grade, students have used the phrase motion energy. This is still acceptable; however, students should be increasingly comfortable with more technical names.)*
- Measurements of properties of objects and their positions (locations) relative to each other provide ways to determine how much of each type of energy is present.
- We can detect some forms of energy with our senses - with thermal energy, we can feel the motion of particles as cold or hot sensations. With kinetic energy we can see the motion of larger objects. Other energy types are stored (potential) in systems and their existence may not be visible until they cause changes to a system.
    - Kinetic – mass of object and the speed of the object
    - Elastic (stored/potential) – distance a spring is stretched and the resistance of the spring (a firmer spring has more resistance to stretching or compressing)
    - Gravitational (stored/potential) – The mass of the two interacting objects (e.g., Earth and an elevated object) and the distance between the objects (e.g., height above Earth's surface).
        - Sometimes this is simplified to the mass of one object and the strength of the gravitational field at a given position (e.g., the mass of an object and the force per unit charge at a given position).
    - Electric (stored/potential) – The amount of charge in each of two interacting objects and the distance between the two charges. (Note: Unlike force, energy does not have a direction associated with it. Students are not expected to know that energy does not have an associated direction.)
    - Chemical (stored/potential) – The strength of the attraction between atoms and the separation between the atoms. *(Note: This information is here for comparison only. Students only need to know that chemical energy is a type of stored energy found in nearly all forms of matter)*
    - Thermal – The average speed of the particles in a substance and the amount of the substance.
- Stored energy is not released until some force is removed that is otherwise preventing the release of the stored energy.
- (*Note: Students are not responsible for calculating energy quantities.*)

Example(s) of Common Student Ideas:

- Only stretched objects have elastic potential energy. Compressed objects do not have elastic potential energy.
- An object loses all its gravitational potential energy as soon as it starts to fall.
- Cold or frozen objects do not have any thermal energy.

6.PS3.3 – Analyze and interpret data to show the relationship between kinetic energy and the mass of an object in motion and its speed.

<u>Big Ideas:</u>

Kinetic energy is the more technical name for motion energy. In a system, the mass of the moving object and the rate of change in the object's position account for the kinetic energy of an object.

<u>Scientific Ideas:</u>

- Energy is required to change the position of an object. A push or pull can transfer energy to an object and initiate that object's change in position.
- As the position of the object changes, the energy added during the push or pull remains with the moving object. This energy ascribed to the moving object is called kinetic energy.
- Speed is a measurement of how quickly the position of an object changes. A stronger push or pull (which represents a greater input of energy) causes greater changes to the motion of an object. Therefore, the faster an object's position is changing, the more kinetic energy it has.
- Objects that are sitting still (at rest) are not undergoing changes to their position and therefore we do not ascribe any kinetic energy to motionless objects.
- The faster an object changes position, the more kinetic energy it possesses.
- If changes to an object's position begins to occur at a slower rate (it slows down) then we ascribe less kinetic energy to the object. Since energy cannot be destroyed, we know that the "lost" kinetic energy has been transferred to another part of the system or surroundings.
- As the speed of a moving object increases, the kinetic energy of that object also increases, however the relative rates of change are not directly proportional. The kinetic energy of an object increases at a greater rate than the speed of an object. If the speed of an object doubles, then the kinetic energy of that object will be four times greater.
- Mass is the measurement of the inertia of an object. Inertia describes how difficult it is to change the motion of an object. If we say that an object is extremely massive, then we are saying that it is very hard to change the motion of an object.
- A larger push or pull is needed to change the position of an object with more mass. Larger pushes or pulls represent larger transfers of energy and therefore we ascribe more kinetic energy to the motion of larger objects.
- Kinetic energy is directly proportional to the mass of an object. An object that is twice as massive will possess twice as much kinetic energy as a different object with a mass that is half as large if the two objects move at the same speed.
- It is not possible to measure the kinetic energy of an object directly.

Example(s) of Common Student Ideas:

- If two objects are traveling at the same speed, they always have the same kinetic energy.
- A falling object does not have kinetic energy.

6.PS3.4 – Conduct an investigation to demonstrate the way that heat (thermal energy) moves among objects through radiation, conduction, or convection.

Big Ideas:

Temperature provides a way to gauge the thermal energy of a system. The thermal energy of a system can change as energy transfers in or out of the system through radiation, conduction, or convection.

Scientific Ideas:

- Temperature is a measurement of the motion of the particles in a substance. Higher temperatures indicate faster moving particles.
- If a warmer object and a cooler object interact, the temperature of the warmer object will decrease and the temperature of the cooler object will increase.
- If all other conditions are equal, a more massive object will undergo a smaller temperature change than a less massive object (e.g., A larger ice cube will cool a drink down more than a smaller ice cube).
- The motion of particles (temperature) and number of particles (mass) are both factors used to ascribe thermal energy to an object.
- When a warmer object and a cooler object physically touch, thermal energy will transfer from the warmer object to the cooler object and cause the temperatures to become more similar.
- An initial input of energy to one region of a fluid (liquid or gas) will immediately increase the motion of the particles in that region. Over time, collisions between the particles will transfer energy and ultimately all particles in the fluid will reach the be moving at the same speed.
- Movement of matter facilitates the transfer of energy through the fluid.
- If a particle (in an object or not) moves, it will emit some form of electromagnetic radiation (light). The wavelength of the radiation depends on the temperature of the particles in the substance. Higher temperature objects emit more energetic photons (shorter wavelengths).
- Since the particles in all materials are in motion, all materials have a tendency to lose energy as the moving particles produce electromagnetic radiation.
- All objects can also absorb some wavelengths of electromagnetic radiation. The electromagnetic radiation that an object absorbs causes the motion of the particles in the object to increase.

- The temperature of an object will increase when it absorbs more electromagnetic radiation than it emits. The temperature of an object will decrease when it emits more energy in the form of electromagnetic radiation than it absorbs.

Example(s) of Common Student Ideas:

- Heat is a substance that flows from warm things to cooler things.
- Cold objects do not have any thermal energy.

Revised (2025 Implementation): 6.PS3.2, 7.PS3.1

6.PS3.2 – Use a model to gather evidence to support changes to a system that can be caused by transfers of sound or thermal energy (i.e., conduction, convection, or radiation).

7.PS3.1 - Plan and carry out an investigation to demonstrate that the interaction between substances can cause chemical reactions that release or store energy.

PS3.B: Conservation of Energy and Energy Transfer

Guiding Questions:

What is meant by the conservation of energy?

How is energy transferred between objects or systems?

The Biggest Ideas

PURPOSE

This component idea explores how energy moves between objects or systems when things about the system change. This includes situations where energy changes from one type to another, as well as when energy transfers in or out of a system (e.g., friction causes a sliding object to slow down).

CENTRAL IDEA(S)

Systems change. Any time a system changes the types of energy or objects possessing the energy change. Energy transfers occur in one of three ways: working, heating, and radiating. Working describes changes caused by physical pushes or pulls, heating is movement of energy through conduction (solids) and convection (fluids), and radiating is movement of energy by electromagnetic radiation. When we know the different forms energy can take in a system, we can explain changes in terms of energy transfers and transformations.

GENERAL PROGRESSION

Students begin this progression by thinking about the way that their skin warms up when they are in the sun. The goal is for students to begin to understand that the sun has an effect on them, even though they are so far away. In late elementary school students encounter the idea that light transfers energy from the Sun to the Earth and that there are other ways that energy can transfer from one place to another. Middle school students treat objects as a system and describe how energy can transfer within the system of objects, or in/out of the system.

K-2 Standards

By the end of grade 2. Sunlight warms Earth's surface.
– NRC, 2012

Progression Across Grade Bands:

The basis of ideas of energy transfer happens in grades K-2 without even mentioning the word energy. Students can go outside and compare the feeling of the sun's warmth in direct sun compared to shade. Students can develop models to explain how the sun causes them to warm up (e.g., when the sun's light can reach them, they feel warm). Student models can reveal some of students' earliest ideas about energy transfer. It is important to draw out that the warmth of the sun is because of the sun's light, but in the shade the light doesn't reach them directly.

In later grades, students will learn that light (i.e., electromagnetic radiation) is one of several different ways that energy can transfer between objects. Energy from the sun travels through space and is the main input of energy to Earth's biosphere and atmosphere.

Current (2018 Implementation): 1.PS3.1

1.PS3.1 – Make observations to determine how sunlight warms Earth's surfaces (sand, soil, rocks, and water)

Big Ideas:

Light from the sun causes things to warm up.

(Note: It is not necessary to discuss energy when covering this standard. In later grades students will learn to associate warming with increases in thermal energy.)

Scientific Ideas:

- When we stand in the sunshine, we feel warmer because of the sun's light shining on us. If we stand in the shade, we do not feel the sun's heat as intensely.
- Just like our bodies, other surfaces will warm up when sunlight shines on them.
- Shadows form when objects block the path of sunlight and prevent the light from reaching the surface. "Shade" is a shadow. (overlap with PS4)
- An object will not warm up as much if it is placed in the shade or a shadow compared to that object placed in the sunshine.
- The object/material that casts a shadow will warm up because the sun still shines on it.
- Some materials do not block the light from the sun (e.g., glass does not produce a shadow) and so these materials do not prevent the sun from changing the temperature of a surface.

Example(s) of Common Student Ideas:

- All materials produce a shadow.
- Shadows are cold.

Revised (2025 Implementation): 1.PS3.1

1.PS3.1 – Make observations to determine how sunlight warms Earth's surfaces (i.e., sand, soil, rocks, and water).

3-5 Standards

By the end of grade 5. Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.

Light also transfers energy from place to place. For example, energy radiated from the sun is transferred to Earth by light. When this light is absorbed, it warms Earth's land, air, and water and facilitates plant growth.

Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy (e.g., moving water driving a spinning turbine which generates electric currents). – NRC, 2012

Progression Across Grade Bands:

Students have seen that things get warmer because of the sunlight. The idea of energy transfer was not mentioned in the earlier grades, but students may have concluded that there must be something from the Sun that reaches them and causes them to warm up.

There are two big ideas for late elementary grades – students will begin to use the word energy and also discuss ways that energy transfers. This should cause students to refine their ideas about how the sun causes things to warm up. Students should now understand that it is energy from the Sun that causes things to warm up and that light transfers the energy from the Sun to the Earth.

Students may realize that energy is present in other circumstances as well – when objects move (including vibrations from sound), in heat (including in the motion of particles). Students are likely to realize that devices that produce motion, sound, or heat require a source of energy. Electrical circuits transfer energy from some source (battery, generator, etc.) to such devices.

Current (2018 Implementation): 3.PS3.1, 3.PS3.2

3.PS3.1 – Recognize that energy is present when objects move; describe the effects of energy transfer from one object to another.

Big Ideas:

Energy can move between the objects in a system. Changes to motion, light, heat, and sound are all examples of energy moving between objects.

Scientific Ideas:

- Moving objects are evidence of energy in a system. We can call this energy "motion energy." Faster moving objects possess larger amounts of energy than slower moving objects.
- Energy transfers can occur when one moving object collides with another object. During the collision, the energy of the objects can change, or the objects' shape can change.
- Collisions can also produce sound or heat the air. These things transfer energy away from the objects involved in the collision (the system) to the surroundings.
- The Sun warms Earth's surfaces because light transfers energy from the Sun to the Earth.
- The light which transfers energy from the Sun to the Earth causes changes on earth – the water and Earth's surfaces warm up. Plants grow when they receive energy. *(Note: Discussions of photosynthesis, plants storing energy, or plants using the energy to make sugars are beyond the scope of grade 3.)*
- A moving object will slow down as energy transfers to the surroundings (e.g., makes noise).

Example(s) of Common Student Ideas:

- As objects slow down, their energy disappears.

3.PS3.2 – Apply scientific ideas to design, test, and refine a device that converts electrical energy to another form of energy, using open or closed simple circuits.

Big Ideas:

Energy can be transferred electrically when an electrical source, such as a battery or generator is connected in a complete circuit to an electrical device, such as a light bulb, speaker, heater, or motor.

Scientific Ideas:

- An electrical source provides energy to an electric circuit. There are different types of sources.
- The source in an electric circuit can transfer energy electrically when the two poles of the source are connected by a material that allows energy to transfer through it. Not all materials allow can transfer energy.
- Electrical devices remove energy from the electrical system (completed circuit). Electrical devices transform the energy in the circuit for different purposes – producing light, sound, heat, or motion.

- Electrical devices decrease the amount of energy in a system (completed circuit) because they transfer the energy out of the system and to the surroundings. If additional energy is not added to the system, then eventually there will not be energy and the devices will no longer perform their intended purpose (e.g., light bulbs will not light up any longer).
- If there is no device in a complete circuit, then energy transfer from one side of the source to the other will cause the material carrying the electricity to overheat or short circuit.
- Energy cannot transfer from the source through electrical devices unless a complete path is provided for the energy transfer. The complete path must go through the device and from one pole of the source to the other.
- Switches can either be open or closed. An open switch creates a break in a circuit. The break in the circuit prevents the flow of energy through the circuit. A closed switch creates a complete circuit which allows the energy to transfer to the devices in the circuit.

<u>Example(s) of Common Student Ideas:</u>

- Switches only work in certain positions of an electrical circuit (e.g., the switch must be placed closer to a particular pole of the battery).
- Devices work as long as they are connected to at least one side of the source.

Revised (2025 Implementation): 3.PS3.1, 3.PS3.2

3.PS3.1 – Make observations of sound, light, heat, and motion to collect evidence that energy is present in a system.

3.PS3.2 – Develop a model to show that the energy can be transferred from place to place by electric currents in a system (e.g., open, closed, simple, parallel, series circuits).

6-8 Standards

By the end of grade 8. When the motion energy of an object changes, there is inevitably some other change in energy at the same time. For example, the friction that causes a moving object to stop also results in an increase in the thermal energy in both surfaces; eventually heat energy is transferred to the surrounding environment as the surfaces cool. Similarly, to make an object start moving or to keep it moving when friction forces transfer energy away from it, energy must be provided from, say, chemical (e.g., burning fuel) or electrical (e.g., an electric motor and a battery) processes.

The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. Energy is transferred out of hotter regions or objects and into colder ones by the processes of conduction, convection, and radiation. – NRC, 2012

Progression Across Grade Bands:

Students were introduced to energy transfer by considering that the sun causes a warming of the Earth's surface. Later in elementary school students developed a very general understanding of energy and that light and electrical currents provide a way for energy from one place to be end up in another place.

Middle grade standards in component idea PS3.a name the different types of energy and the properties of a system that account for the various types. It is important for middle school students to be able to define a system when they consider energy transfers. For example, a car uses chemical energy in gasoline to produce motion and maintain motion, but also loses some of the energy to its surroundings.

As students think about energy transfers and transformations, they also discuss specific mechanisms that cause increases and decreases in thermal energy.

Current (2018 Implementation): 6.PS3.2

6.PS3.2 – Construct a scientific explanation of the transformations between potential and kinetic energy.

Big Ideas:

After accounting for energy transfers into or out of the system, increases or decreases in potential energy within a system are matched by decreases or increases, respectively, in the kinetic energy in a system.

Scientific Ideas:

- Potential energy refers to various types of stored energy in a system.
- There are different agents which store potential energy in a system: springs and other elastic objects store energy, gravitational fields and magnetic fields store energy, molecules store chemical energy. *(Note: Students have not discussed bonding. Discussions of chemical energy should be limited to general ideas that food, batteries, gasoline, etc. that can release energy).*
- Moving objects are said to possess kinetic energy, which may also be referred to as motion energy. An object's potential energy increases as it speeds up.
- Agents (e.g., gravitational fields) that possess stored energy and can exert forces on other objects are able to change the motion of the other object.
    - Forces can increase the motion of objects (potential decreases, kinetic increases)
    - Forces can decrease the motion of objects (potential increase, kinetic decreases)
- Forces acting on objects can transform the energy in a system. (E.g., An object that is thrown upward is slowed down by a gravitational force acting against it. An object that is falling downward speeds up because of Earth's gravitation field pulling the object towards Earth's surface.)
- When comparing energy present before and after energy transformations, the total amount of energy (potential + kinetic) will not change when accounting for energy transfers into or out of the system.
- Energy can transfer in/out of a system during an energy transformation. When this occurs, the energy transferred in/out of the system will equal the difference between the total energies before and after a transformation (e.g., an object sliding down a hill will heat the surface and so the object's final kinetic energy will not equal its initial potential energy).

Example(s) of Common Student Ideas:

- Energy can be transformed into a force.
- Energy can be created or destroyed.

Revised (2025 Implementation): *Secondary to 6.PS3.1*

PS3.C: Relationship Between Energy, Forces, and Fields

Guiding Question:

How are forces related to energy?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to connect forces to energy. Forces are one way to transfer energy to or away from objects and systems.

CENTRAL IDEA(S)

Forces – pushes and pulls – can change the motion or position of objects in a system. Since motion and position relate directly to energy, we can conclude that forces are a way to change an object's energy. For moving objects, a push or pull that speeds up an object transfers energy to that object. Forces that slow down an object transfer energy away from the object. When objects interact, there are always pairs of forces.

GENERAL PROGRESSION

Students begin this progression by noticing that pushes and pulls cause things to move and that collisions (interactions) always involve pairs of forces. Students learn about non-contact (field) forces by investigating magnets and describing how the pairs of forces exist. Also, in grades 3-5 students learn that forces transfer energy. By middle school students apply their understanding of the different types of energy to be able to explain how forces transfer or transform the energy of a system.

K-2 Standards

By the end of grade 2. A bigger push or pull makes things go faster. Faster speeds during a collision can cause a bigger change in shape of the colliding objects. – NRC, 2012

Progression Across Grade Bands:

Students can push a toy car into a layer of clay applied to the base of a wall to investigate this component idea. This setup allows students to make a sequence of two observations. The first observation is that pushing the car can cause it to move and if they push harder the car will move faster. The second observation is that the car will leave a mark where it runs into clay. If the car is moving faster, because it was pushed harder, it will leave a deeper mark in the clay. Students should be allowed to notice/wonder as they engage with the cars and clay. Do they notice differences in the marks made in the clay? Can they uncover the pattern that deeper marks happen when they push harder? Can they develop models, such as drawings, which communicate their explanation of this cause-and-effect relationship and the pushes involved?

In this progression students should understand that there are always two pushes that occur when objects interact. Collisions are one type of interaction and the setup described above should allow students to see evidence of the two pushes evidence that occur. The mark that the toy car leaves on the piece of clay is evidence that the car pushed on the clay. At the same time, the motion of the toy car changes. This change in motion is evidence that the clay/wall must have pushed on the toy car. The two pushes we see are the car pushing on the clay and the clay pushing on the car.

In later grades, students begin to discuss energy and their understanding of this scenario will evolve. They will come to understand that the force (push) on the car transfers energy to the car and the forces involved during the collision transfer this energy to the surroundings. They will also understand that stronger forces transfer more energy to the car and later to the surroundings.

Current (2018 Implementation): 2.PS3.1

2.PS3.1 – Demonstrate how a stronger push or pull makes things go faster and how faster speeds during a collision can cause a bigger change in the shape of the colliding objects.

Big Ideas:

Pushes or pulls on an object (forces) can cause the object's motion to change or cause the object's shape to change – these are precursory indicators of energy changes.

Scientific Ideas:

- When we push or pull on something we can cause changes to the shape or motion of the object – speed up, slow down.
- Pushes and pulls cause changes to objects either by changing the shape of the object or changing the motion of the object.
- Pushes and pulls can have different strengths – stronger, weaker.
- When we push on something we can make it move or change its speed or shape.
- Objects can move at different speeds – faster moving objects will move further in a certain amount of time than slower moving objects.
- When objects run into each other, they push on each other.
- Pushes or pulls can cause the shape of an object to change. While changing the shape of an object might include causing dents in the object, it might also include knocking a group of stacked objects over or other similar rearrangements of objects.
- Descriptions of moving objects include both how fast the object is moving and which direction they are headed.
- Sometimes pushes change the speed of an object. Sometimes pushes change the direction an object is heading and sometimes pushes change both the speed and direction.

<u>Example(s) of Common Student Ideas:</u>

- The only way an object has forces acting upon it is when we are physically touching that object.

Revised (2025 Implementation): 2.PS3.1

2.PS3.1 – Demonstrate how a stronger push or pull makes things go faster and how faster speeds during a collision can cause a bigger change in the shape of the colliding objects.

3-5 Standards

By the end of grade 5. When objects collide, the contact forces transfer energy so as to change the objects' motions. Magnets can exert forces on other magnets or on magnetizable materials, causing energy transfer between them (e.g., leading to changes in motion) even when the objects are not touching. – NRC, 2012

Progression Across Grade Bands:

The goal for this grade band is for students to understand the connection between forces and energy, which are both new topics. Students learn that faster moving objects have more motion energy and that forces can have different strengths. This component puts these two pieces of information together; A push that causes something to move has transferred energy to that object. Consider revisiting the toy car setup described in the K-2 progression above, allowing students to revise their explanations to include their understanding of forces and energy.

Students have already seen that pushes and pulls occur in pairs when objects interact. They may have used the toy car setup to gather evidence of pairs of forces. This setup provided concrete evidence of all aspects; there was a visible collision, a mark in the clay, and the car's motion changed.

Students learn about fields by examining magnets in this grade band. Iron filings are a useful way for students to see evidence of the magnetic fields and visualize how the fields behave when magnets interact. Just like the toy car setup, the magnetic interaction involves a pair of forces, however this pair of forces exists even when the magnets do not touch. A dynamics cart or a toy car with a magnet hot glued on top can show how magnetic fields exert forces that cause objects to move. The force from each car's magnet causes the other car to move as the stored energy from each field is transformed to motion energy in the other car.

Current (2018 Implementation): 3.PS3.3

3.PS3.3 – Evaluate how magnets cause changes in the motion and position of objects, even when the objects are not touching the magnet.

Big Ideas:

Magnets exert forces on objects and these forces cause changes in the energy of objects by changing the motion and/or position of the objects.

Scientific Ideas:

- A force is a push or a pull on an object and has both a strength and a direction.
- Objects can push or pull on each other even if they don't physically touch.

- A force can change the motion of an object by causing it to start moving, speed up, or slow down.
- If the motion of an object changes because of a force, then there has been a change to the energy in the system. (I.e., If an object begins moving, we say that its motion energy is increasing. If the object slows down, its motion energy decreases.)
- A force that changes the position of an object represents a change to the energy of the object.
    - An object that changes its position horizontally has motion energy as it moves from its original position to its new position.
    - An object that changes its position vertically gains motion energy while it is being lifted and this motion energy becomes stored energy if the object remains lifted off of a surface.
- Forces (including magnets) can push or pull other objects before the objects are touching and therefore it is possible for magnets to change the energies in a system even if they don't touch the objects in the system.

Example(s) of Common Student Ideas:

- Forces require contact.

Revised (2025 Implementation): 3.PS3.3, 4.PS3.2

3.PS3.3 – Evaluate how magnets cause changes in the motion and position of objects, even when the objects are not touching the magnet.

4.PS3.2 – Carry out an investigation to show how faster speeds during a collision can cause a bigger change in the shape of the colliding objects.

6-8 Standards

By the end of grade 8. When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. For example, when energy is transferred to an Earth-object system as an object is raised, the gravitational field energy of the system increases. This energy is released as the object falls; the mechanism of this release is the gravitational force. Likewise, two magnetic and electrically charged objects interacting at a distance exert forces on each other that can transfer energy between the interacting objects. – NRC, 2012

Progression Across Grade Bands:

In the earlier grades students may have seen that forces exist in pairs. In K-2 students could find evidence for pairs of forces as toy cars ran into clay. In 3-5 students could observe pairs of forces in magnetic fields. By late elementary school, students learn general ideas about forces and energy.

In the middle grades, students can think of different types of energy as different accounts (PS3.A) with different ways to transfer energy between these accounts (PS3.B). They learn to associate features of systems with different types of energy. For example, motion indicates kinetic energy, and a stretched rubber band indicates potential (stored) energy. Using their understanding of the properties of different types of energy, students should be able to describe the forces that transfer energy in everyday systems; As the rubber band snaps back to its original shape, it pushes on the toy car launcher. The force of the launcher transfers stored energy to the toy car which begins to move, indicating the transformation to kinetic energy.

Current (2018 Implementation): Secondary to 6.PS3.1

Revised (2025 Implementation): Secondary to 8.PS2.6

PS3.D: Energy in Chemical Processes and Everyday Life

Guiding Questions:

How do food and fuel provide energy?

If energy is conserved, why do people say it is produced or used?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to consider the way that humans and living things capture and store energy.

CENTRAL IDEA(S)

Sustaining life and controlling society's use of energy require the ability to capture and store energy. Food and fuel are captured energy. Plants capture and store the Sun's energy. The food we eat allows us to use this stored energy. Humans design devices and systems to control energy storage and release. Efficient devices require less energy capture and storage.

GENERAL PROGRESSION

Before they reach school age, students may have firsthand experiences with energy. For example, cell phone batteries "die," but can be recharged by plugging them in or cars and lawnmowers stop running when they run out of gas. These experiences will begin to form the way that students talk and think about energy.

This progression begins with students observing that friction produces warmth. Later, students consider that plants capture and store energy from the sun. We receive some of this energy when we eat plants or other things that eat plants. Movement (e.g., rubbing hands) releases some of the energy from our food. In the middle grades students talk about specific types of energy and chemicals that make the capture and transfer of energy possible.

K-2 Standards

By the end of grade 2. When two objects rub against each other, this interaction is called friction. Friction between two surfaces can warm of both of them (e.g., rubbing hands together). There are ways to reduce the friction between two objects. – NRC, 2012

Progression Across Grade Bands:

Students will talk about warming in the early grades, instead of talking about energy. This component idea calls for students to notice that friction makes things warm up, such as warming their hands by rubbing them together. Another component idea talks about the Sun warming the Earth's surface.

If students place a small amount of soap on their hands, they may notice that it is easier to rub their hands together and that their hands don't warm up as quickly. Before introducing the technical "term" friction, students should be challenged to develop an explanation for this experience. Student explanations are likely to include words like "slippery" which can be used to develop a conceptual understanding of why there is less heat before introducing the word friction.

Students may believe that by rubbing things together they are "producing warmth." This thinking sounds like everyday language which describes that windmills or solar panels make energy. Over time the goal of this component idea is to help students understand that these are all examples of capturing and transforming energy that is already present somewhere. For example, the warmth created when rubbing their hands together comes from the energy, they received from the food they ate.

Current (2018 Implementation): 2.PS3.2

2.PS3.2 – Make observations and conduct experiments to provide evidence that friction produces heat and reduces or increases the motion of an object.

<u>Big Ideas:</u>

When two things rub against each other, the movement causes the surfaces to warm up and can cause the motion of the objects to change.

(Note: Limit discussions to objects that slide past each other, not rolling objects or wheeled objects.)

<u>Scientific Ideas:</u>

- When two surfaces rub against each other or slide past each other, they will warm up.

- Not all surfaces warm up the same amount. Some surfaces will warm up more than others when they are rubbed together.
- Surfaces that do not slide well will warm up more than surfaces that slide past each other easily.
- It is possible to change the amount that a surface warms up by doing things that help the surface slide more easily.
- Pushing two surfaces together makes it harder to slide those surfaces past each other.
- Friction is a type of push or pull and can change the motion of an object.
    - Friction can cause objects to slow down – a block of wood sliding across a desktop, or brakes rubbing on a bike rim.
    - Friction helps objects start moving – trying to walk across ice or a slippery floor compared to walking on a dry sidewalk.

Example(s) of Common Student Ideas:

- Friction is always unhelpful/negative.

Revised (2025 Implementation): 2.PS3.2

2.PS3.2 – Make observations and conduct experiments to provide evidence that friction produces heat and reduces or increases the motion of an object.

3-5 Standards

By the end of grade 5. The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use—for example, the stored energy of water behind a dam is released so that it flows downhill and drives a turbine generator to produce electricity. Food and fuel also release energy when they are digested or burned. When machines or animals "use" energy (e.g., to move around), most often the energy is transferred to heat the surrounding environment.

The energy released by burning fuel or digesting food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (Boundary: The fact that plants capture energy from sunlight is introduced at this grade level, but details of photosynthesis are not.)

It is important to be able to concentrate energy so that it is available for use where and when it is needed. For example, batteries are physically transportable energy storage devices, whereas electricity generated by power plants is transferred from place to place through distribution systems. – NRC, 2012

Progression Across Grade Bands:

The word energy has been avoided in earlier grades. Instead, students discussed warmth – warming from the sun (PS3.a) or from rubbing surfaces together. Though standards in this grade band do not define specific forms of energy such as kinetic energy, elastic potential energy, etc., the standards do introduce the concepts of motion energy and stored energy, as well as the idea that energy can be used for practical purposes. The idea of warmth re-emerges in this component idea as students uncover that motion energy produces friction which warms up the surroundings and causes a decrease in the amount of energy that can be stored again.

In this grade band, students begin to clarify language. For example, "producing energy" refers to capturing energy and storing the energy or using it for some purpose. To "use energy" refers to accessing energy that has been stored and accomplishing something helpful with the energy. In either case, the law of conservation of energy is still valid. Captured energy was already present in the universe.

Current (2018 Implementation): 4.PS3.2, 4.PS3.3

4.PS3.2 – Observe and explain the relationship between potential energy and kinetic energy.

<u>Big Ideas:</u>

Motion energy comes from stored energy that has been transformed by an animal or machine. It is possible to capture and store motion energy, but motion energy will also warm up the surroundings which means that there is less energy available than the initial input.

Scientific Ideas:

- Potential energy refers to energy that is stored.
- Kinetic energy refers to motion energy.
- Many different devices/systems can store energy –
    - stretching a rubber band or blowing up a balloon store energy by stretching an elastic material.
    - Lifting an object to a higher height stores energy until the object is released and falls.
    - Plants capture and store energy from the sun as they grow.
    - Burning fuels releases energy that was originally stored by plants.
    - Batteries store energy produced by a power plant.
- Devices exist that can make objects move by transforming stored energy.
- The motion energy of a moving object came from a source of stored energy.
- Motion energy can transform back into stored energy, but there will be less stored energy than initially because some of the stored energy warms up the environment.

Example(s) of Common Student Ideas:

- Only objects that are raised off the ground have potential energy.
- Any object that can "potentially" move or be put in motion has potential energy.

4.PS3.3 – Describe how stored energy can be converted into another form for practical use.

Big Ideas:

Converting energy to a practical use involves the process of transforming energy that has been stored into another type of energy that is employed for a specific purpose.

Scientific Ideas:

- Many different devices/systems can store energy –
    - stretching a rubber band or blowing up a balloon store energy by stretching an elastic material.
    - Lifting an object to a higher height stores energy until the object is released and falls.
    - Plants capture and store energy from the sun as they grow.
    - Burning fuels releases energy that was originally stored by plants.
    - Batteries store energy produced by a power plant.

- “Capturing” energy refers to converting energy that is already present into stored energy.
- It is possible to release energy that has been stored.
- “Releasing energy” refers to a process that converts energy that has been stored previously to another form.
- Some systems are designed to convert energy for immediate use (e.g., a water wheel might drive a system of belts or gears that power machinery in different types of watermills).
- Other systems capture energy and transform it in a way that it can be stored.

Example(s) of Common Student Ideas:

- Energy disappears when it transforms.
- Stored energy is a substance that is stored in a system.

Revised (2025 Implementation): 4.PS3.2

4.PS3.2 – Carry out an investigation to show how faster speeds during a collision can cause a bigger change in the shape of the colliding objects.

6-8 Standards

By the end of grade 8. The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (Boundary: Further details of the photosynthesis process are not taught at this grade level.)

Both the burning of fuel and cellular digestion in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.

Machines can be made more efficient, that is, require less fuel input to perform a given task, by reducing friction between their moving parts and through aerodynamic design. Friction increases energy transfer to the surrounding environment by heating the affected materials. – NRC, 2012

Progression Across Grade Bands:

In the middle grades students become familiar with different types of energy and energy transfer. When plants grow, they produce the food molecules that other organisms eat. Plants require an input of energy, and the sun supplies that energy. Other organisms "release" the energy that plants store in the compounds that they produce during photosynthesis. In all instances, releases of energy stored in food happen in chemical reactions that rearrange the matter plants capture in photosynthesis.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): 7.PS3.2

7.PS3.2 – Develop a model to explain how food is utilized through chemical reactions to form new molecules that support growth, resulting in the release of energy as matter moves through an organism.

PS4.A: Wave Properties

Guiding Question:

What are the characteristic properties and behaviors of waves?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to understand the features of waves – both pulses and simple waves – as well as the behaviors that we observe when waves interact with each other or their surroundings.

CENTRAL IDEA(S)

Waves transfer energy. A wave forms when a push or pull transfers energy to a medium that a wave can travel through. Many things can produce energy pulses – objects striking a surface, vibrations of vocal cords, shifting of tectonic plates, the rearrangement of subatomic particles, etc. When a pulse repeats it produces a simple wave pattern with the features that are commonly associated with waves (e.g., frequency, wavelength). The wavelength, and therefore speed, of a wave is influenced by properties of the medium that transmits the wave.

GENERAL PROGRESSION

In elementary school students begin to learn about waves by studying wave pulses – single waves. Students first explore waves in water to see that waves occur when a disturbance occurs. Later, students can use objects like ropes and springs to see how waves interact with each other. In the middle grades students will spend more time exploring the simple waves which are waves that occur when a disturbance repeats at a constant interval.

K-2 Standards

By the end of grade 2. Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; it does not move in the direction of the wave—observe, for example, a bobbing cork or seabird—except when the water meets the beach. Sound can make matter vibrate, and vibrating matter can make sound. – NRC, 2012

Progression Across Grade Bands:

Students can make waves by dropping objects into water or other fluids. Students should see that waves only form when something pushes or pulls on the surface of the liquid and that a single wave pulse forms when the surface of the liquid is only disturbed one time. If students repeatedly disturb the surface, then they can produce a series of wave pulses. Students should also observe how the wave interacts with objects as it passes by. Placing small floating objects onto the surface of the water allows students to see that the wave pushes the objects up and down as it passes, but it does not push the object sideways.

Sound waves are beyond the scope of the earliest grades; however, students should see that sounds cause things to vibrate and that objects that vibrating objects produce sound. This can be done by placing grains of rice on a piece of paper held off of a table. Students may connect those shorter sounds (e.g., clapping once, clicking their tongue) is like wave pulses where the disturbance happens only one time and that sounds that are sustained (e.g., humming) are like the repeated disturbance of the water that creates a series of waves pulses.

(Note: Waves at the beach are a phenomenon that occurs when a wave traveling through deeper water runs into the shallow shore. This phenomenon is a behavior of a wave that is not intended in this grade band. Limit discussions to waves that travel through a medium without interference from other surfaces.)

Current (2018 Implementation): 2.PS4.1, 2.PS4.3

2.PS4.1 – Plan and conduct an investigation to demonstrate the cause-and-effect relationship between vibrating materials (tuning forks, water, bells) and sound.

Big Ideas:

Materials that vibrate may produce a sound and that sound can, in turn, make other things vibrate.

Scientific Ideas:

- When a material vibrates, it moves back and forth repeatedly.

- Vibrations can be fast or slow.
- Vibrations can be sustained for different amounts of time – a clap, repeated clapping, humming.
- Some vibrating materials will produce a noise that can be heard.
- When the vibrating object stops moving or is not allowed to vibrate, it will not produce a sound.
- Sounds can cause objects to vibrate – e.g., grains of rice placed on a drumhead or piece of paper near a sound source.
- Different sounds cause different patterns in the way that objects vibrate.

Example(s) of Common Student Ideas:

- Only sounds you can physically feel are vibrations.

2.PS4.3 – Observe and demonstrate that waves move in regular patterns of motion by disturbing the surface of deep and shallow water.

Big Ideas:

When the surface of a liquid is disturbed, a wave will form and move across the liquid's surface.

(Note: The focus of this standard should be on waves in deeper water, since those in shallow water may interact with other surfaces.)

Scientific Ideas:

- Anything that pushes or pulls on the surface of a liquid will cause movement in the liquid's surface.
- A single push or pull on the surface will create a single movement in the surface. The surface will move up and down.
- The push or pull will create a wave that travels across the surface, away from where the push or pull happened until it runs into some other object or surface. (*Note: Students may have questions about the wave bouncing off of the other surface. These are a good opportunity to introduce the idea of reflection, but it is not necessary to deeply explore that phenomenon.*)
- If a surface is repeatedly disturbed, then waves will travel away from the point where the disturbance occurs with a consistent pattern. E.g., if water droplets fall onto the surface at a rate of 1 drop per second, then waves will cross a distant point on the water's surface at a rate of 1 wave per second.
- The wave travels sideways across the surface of the water, but the water actually moves up and down.

Example(s) of Common Student Ideas:

- Waves in water will move a floating object forward.

Revised (2025 Implementation): 2.PS3.2

2.PS4.1 – Plan and conduct investigations to demonstrate the cause-and-effect relationship between vibrating materials and sound.

3-5 Standards

By the end of grade 5. Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks). Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.)

Earthquakes cause seismic waves, which are waves of motion in Earth's crust. – NRC, 2012

Progression Across Grade Bands:

Earlier standards call for students to explore waves in water and sound. The key ideas students should have taken from these experiences are that disturbances cause waves, and that sound is a vibration. Water was a good medium to produce waves in earlier grades, but creating waves that travel across strings, ropes, or springs may better reveal the ideas in these standards.

Instead of dropping objects onto the surface of a liquid, students can produce wave pulses in ropes with quick up and down motions. It may be helpful for students to use analogy maps to relate the waves they produce in the rope back to the waves from earlier grades.

Interactions between waves are a key part of the 3-5 grade band. For students to observe how waves interact, pairs of students can simultaneously introduce waves into the rope. This can be done standing, or with the rope laid across a smooth floor, where tiles may even provide a reference for the height of waves (amplitude) and the length of the waves.

In later grades students will spend more time with mathematical models of waves. The models used in this grade band should capture the properties of the actual waves.

Current (2018 Implementation): 4.PS4.1

4.PS4.1 – Use a model of a simple wave to explain regular patterns of amplitude, wavelength, and direction.

Big Ideas:

Waves have measurable properties that vary and depend on the actions that caused the wave to form. It is possible to create a representation of a waves properties.

Scientific Ideas:

- Forces cause changes in the motion or position of an object. E.g., A big force that moves the end of a rope up-and-down causes a big change in the position of a portion of a rope, whereas a smaller force causes less movement in the rope.
- Forces (pushes or pulls on the medium) introduce energy which we can observe because the motion or position of the rope changes.
- A wave forms from a disturbance that pushes or pulls on a medium and causes it to move. If the disturbance occurs only once, then only a single wave pulse will form. If the disturbances happen repeatedly and with a pattern, then a simple wave forms.
- Waves travel away from where a disturbance occurs.
- For a simple wave, each time that a disturbance occurs, an additional wave will form and the distance between the crests is the wavelength.
- The wavelength will not change if the timing between disturbances does not change.
- Stronger forces push/pull harder on the medium. Because the pushing and pulling is stronger, the waves will be taller than relatively weaker forces on the same medium.
- Stronger forces transfer more energy to a system.

Example(s) of Common Student Ideas:

- Waves only travel through liquids.
- Waves always form in water.

Revised (2025 Implementation): 4.PS4.1

4.PS4.1 – Use a model of a simple wave to describe amplitude, wavelength, and explain how waves can add or cancel each other as they cross.

6-8 Standards

By the end of grade 8. A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. A sound wave needs a medium through which it is transmitted.

Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. – NRC, 2012

Progression Across Grade Bands:

Many of the earlier concepts about waves have focused on wave pulses. In middle school, students spend more time looking at simple waves. A simple wave is a repeating series of wave pulses that happens when a disturbance occurs at a regular interval.

From the earliest grades, students should understand that the number of wave pulses matches the number of disturbances. This means that a repeating series of wave pulses must be caused by a disturbance that repeats and that the frequency of the wave will match the frequency of the source. Other properties of the wave are a result of the medium. For example, the wavelength of a wave changes depending on the material that the wave is traveling through. Changing the wavelength of a wave also changes the speed of the wave.

Current (2018 Implementation): 8.PS4.1

8.PS4.1 – Develop and use models to represent the basic properties of waves including frequency, amplitude, wavelength, and speed.

<u>Big Ideas:</u>

The diagram of a wave represents details about the source that creates a wave as well as behaviors of the wave as it travels through and across different media.

<u>Scientific Ideas:</u>

- A wave forms when a medium is disturbed.
- The wave will travel away from the point of the disturbance.
- A simple wave forms when a disturbance is repeated at a set frequency. The successive wave crests will have uniform spacing and the distance between the crests is the wavelength.
- For the same medium, forces that produce waves less often (lower frequency) will have a greater distances between crests than waves produced more often.
- Waves travel at different speeds through different media.

- The speed of a wave changes when the wave crosses a boundary between two different media but does not change when traveling through a uniform medium.
- Waves produced by disturbances occurring at the same interval (equal frequencies) will have different wavelengths in different materials depending on how quickly the media transmits the wave.
- A wave's frequency is determined by how quickly the source of the wave vibrates. For example, if a source vibrates back and forth ten times per second it will have a frequency of 10hz.
- When a wave transitions from one medium to another, its frequency (the rate of the original pulse creation) cannot change and therefore changes in the speed of a wave are a result of changes to the wavelength of the wave.

Example(s) of Common Student Ideas:

- Waves slow down as they move through a medium, just like objects do.

Revised (2025 Implementation): 8.PS4.1

8.PS4.1 – Develop and use models to represent the basic properties of waves in a system including frequency, amplitude, wavelength, and speed.

PS4.B: Electromagnetic Radiation

Guiding Questions:

What is light?
How can one explain the varied effects that involve light?
What other forms of electromagnetic radiation are there?

The Biggest Ideas

Purpose

The purpose of this component idea focuses on electromagnetic radiation which behaves like other waves, but also has unique behaviors.

Central Idea(s)

Visible light is the type of electromagnetic light that we are most familiar with because it interacts with objects and our eyes allowing us to see. The spectrum of electromagnetic radiation includes much more than just visible light, such as microwaves, infrared light, and radio waves. All these types of electromagnetic radiation have behaviors that we see in other types of waves as well as behaviors that are unique to electromagnetic radiation. Different wavelengths of electromagnetic radiation interact with materials in unique ways.

General Progression

This progression begins by helping students to understand that we can only see objects if there is light shining on them. That light must then be able to reach our eyes for us to see the objects. Students also see that some materials let light pass through them so that we can see things on the other side of the material. Later in elementary school, students consider how different colored light sources affect the color of the objects we see and the way that light interacts with different surfaces. In middle school students expand their discussions beyond just visible light and talk about other frequencies of electromagnetic light and begin to explore differences between light waves and mechanical waves.

K-2 Standards

By the end of grade 2. Objects can be seen only when light is available to illuminate them. Very hot objects give off light (e.g., a fire, the sun).

Some materials allow light to pass through them, others allow only some light through, and others block all the light and create a dark shadow on any surface beyond them (i.e., on the other side of the light source), where the light cannot reach. Mirrors and prisms can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) – NRC, 2012

Progression Across Grade Bands:

Students build their understanding about electromagnetic radiation by starting with visible light and observing patterns in the types of things that produce light. In all cases, students should realize that light comes from things that heat up – things like incandescent light bulbs, candles, or the sun provide familiar examples. These observations overlap with ideas about energy transfer (PS3.A) where students come to understand that sunlight causes things to warm up. In later grades students, when students become familiar with the internal structure of atoms, they will be able to connect these early ideas about the way that bursts of applied to individual atoms produces light.

Light behaves like a wave, and while students in these earliest grades are not expected to understand that light has wave properties, it may help students understand that light spreads from a source in the same way that a wave travels outward from the disturbance that creates it. Using rays (arrows) to show the path of light in early grades will help students represent phenomena such as refraction in later grades. Materials interact differently with light. Different materials may absorb light, reflect light, or allow light to pass through them. By observing transparent and opaque materials, students gain a foundation to understand more complicated phenomenon around light including how we perceive the color of objects and the way that technologies, such as X-rays, utilize differences in the way that materials may transmit or absorb certain frequencies of electromagnetic radiation.

Current (2018 Implementation): 1.PS4.1, 1.PS4.2

1.PS4.1 – Use a model to describe how light is required to make objects visible. Summarize how illumination could be from an external light source or by an object giving off its own light.

Big Ideas:

Some objects can emit light, and this light illuminates a space making things visible.

Scientific Ideas:

- When some materials get hot enough, they can produce their own light.
- The light that an object produces moves outward from the source and fills the space immediately. Arrows, called rays, are a helpful way to represent the path that light travels away from a source. Rays are drawn as straight lines.
- As the light travels outward from the source, it can make other things visible.
- Without a source of light, objects are not visible.
- Objects are only visible when there is enough light to illuminate them and the light that illuminates the object bounces off the object and reaches our eyes.
- We can only see objects when light has bounced off those objects and into our eyes.
- There can be varying levels of light and sometimes there is not enough light in an area to see all objects or see details in the object.
- More rays (arrows) or rays that are closer together represent brighter lights.
- Light becomes less bright as you get further from a light source because the rays, which travel in straight lines, spread out and less rays reach objects that are further away from the source.

Example(s) of Common Student Ideas:

- We can still see things without light.

1.PS4.2 – Determine the effect of placing objects made with different materials (transparent, translucent, opaque, and reflective) in the path of a beam of light.

Big Ideas:

Materials interact with light in different ways. Using ray diagrams to represent these different interactions helps explain related phenomena such as creating shadows and warming up.

Scientific Ideas:

- Light travels away from the source that produces it. Arrows, called rays, are a helpful way to represent the path that light travels away from a source.
- As the light travels outwards, it will reach different objects.
- Some materials allow light to pass through them. All rays that strike the object pass through the object. Objects that allow light to pass through do not create shadows.
- Some materials block light. Rays of light do not pass through these objects. Objects that block the path of light create shadows behind them. The rays of light that these objects absorb can cause them to warm up.
- Some materials block only a portion of the light that reaches them. These objects create areas of partial shadows. Some rays of light pass through them and some are blocked.

- Some materials change the direction that light is traveling. The rays of light that hit these materials "bounce off" the objects. These objects warm up less because they are redirecting most of the light and not absorbing the light.

Example(s) of Common Student Ideas:

- All materials will create a shadow.

Revised (2025 Implementation): 1.PS4.1, 1.PS4.2

1.PS4.1 – Make observations to construct an evidence-based account that objects are visible when light shines on them or if they produce their own light (e.g., very hot objects), and that different amounts of light influence what we can see.

1.PS4.2 - Conduct an investigation to describe how the path of a beam of light can be changed by interactions with different materials (i.e., light passes through, some light passes through, light changes directions, or light is blocked which can cause shadows).

3-5 Standards

By the end of grade 5. A great deal of light travels through space to Earth from the sun and from distant stars.

An object can be seen when light reflected from its surface enters the eyes; the color people see depends on the color of the available light sources as well as the properties of the surface. (Boundary: This phenomenon is observed, but no attempt is made to discuss what confers the color reflection and absorption properties on a surface. The stress is on understanding that light traveling from the object to the eye determines what is seen.)

Because lenses bend light beams, they can be used, singly or in combination, to provide magnified images of objects too small or too far away to be seen with the naked eye. – NRC, 2012

Progression Across Grade Bands:

In earlier grades students began to use ray diagrams to represent the path of light and phenomena associated with the way that light interacts with different objects.

Eventually students will learn about all forms of electromagnetic radiation, but throughout elementary school, students will only consider visible light because it is the electromagnetic radiation. In the 3-5 grade band students prepare for the idea that there are different types of electromagnetic radiation by learning that there are different colors of light and when these colors combine, they create white light. The colors of light are all part of a portion of the electromagnetic spectrum that we call visible light, but this spectrum extends beyond visible light to both higher energy (e.g., ultraviolet) and lower energy (e.g., infrared) electromagnetic radiation.

Current (2018 Implementation): 4.PS4.2

4.PS4.2 – Describe how the colors of available light sources and bending of light waves determine what we see.

Big Ideas:

The appearance of the objects that we see depends on the properties of light as well the properties of the objects.

Scientific Ideas:

- Light travels in straight lines away from a source and we represent the path of light using lines called rays. An object can be seen when rays of light travel from the object to an observer's eyes.
- Light that we perceive as white light is a blend of three primary colors of light (red, green, and blue). We perceive the full spectrum of light (ROYGBIV) as white light.
- Different sources of light can emit some or all colors of light and we perceive the color of these sources of light based on the colors of light they emit.
- Rays (arrows), including arrows of different colors can represent the light that a source emits. These rays of light travel along straight paths away from the source.
- Materials interact in different ways with the light that reaches them, including absorbing the light, allowing some/all of the light to pass through, or changing the path or direction of travel of the light.
- The perceived color of an object is caused by the color of light reflected by the object which then enters our eyes. E.g., objects that appear red when they reflect light.
- Objects appear white when they reflect or emit red, green, and blue light. Objects appear black when they absorb the red, green, and blue light that strikes them.
- Some materials absorb some colors of light that strike them and reflect other colors of light. The colors of light that a material absorbs or reflects under certain conditions are a property of the material and confer the color of the material.
- The appearance of an object can change based on the available colors of light. E.g., If any object that typically reflects red light is illuminated by a source of light that does not emit red light, the object will appear black.
- Any time that a ray of light crosses a boundary between two different media/materials, the path of a ray of light will change (e.g., a ray of light that leaves the air, and travels into glass, or leaves glass and travels into the air).
- The degree to which a material changes the path of a ray of light is a property of that material/medium.
- Devices such as magnifying glasses, glasses, telescopes, and microscopes utilize the bending of light to cause objects to appear larger or smaller than their actual size.

Example(s) of Common Student Ideas:

- We can still see when there is no available light.

Revised (2025 Implementation): 4.PS4.2

4.PS4.2 – Construct an explanation for how the colors of available light sources and the bending of light waves determine what we see.

6-8 Standards

By the end of grade 8. When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.

The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. Lenses and prisms are applications of this effect.

A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media (prisms). However, because light can travel through space, it cannot be a matter wave, like sound or water waves. – NRC, 2012

Progression Across Grade Bands:

This component idea, dedicated to electromagnetism has only addressed one type of electromagnetic radiation prior to middle school (e.g., visible light). Using tools like an optics bench can help students observe how light bends when it travels through lenses or the ability of light to transmit through different colors and types of materials.

Though seemingly unrelated, standards about motors and solenoids support this component idea because they help students understand that electric currents produce magnetic fields and vice versa. The principles that allow those devices to work help students understand the ways that electric fields and magnetic fields are interconnected. It is this relationship between electricity and magnetism that allows electromagnetic radiation to propagate through places where there are no particles to transmit the wave. In this grade band students should apply their understanding of waves from PS4.A to electromagnetism to understand that the differences between electromagnetic waves and their interactions with matter can be understood using wave models.

Current (2018 Implementation): 8.PS4.2

8.PS4.2 – Compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission, absorption, and their behavior through a vacuum and/or various media.

Big Ideas:

Many of the properties of electromagnetic waves are shared with mechanical waves and the processes that form each type of wave are relatively analogous.

Scientific Ideas:

- There are many different types of electromagnetic radiation and visible light represents only a small portion of these different types.
- Simple waves are created by disturbances that happen at a consistent frequency. Mechanical waves are created by disturbances that push and pull-on different forms of matter (e.g., water, air). Electromagnetic waves are created by disturbances to electric and magnetic fields.
- Wave models are an effective way to represent differences in electromagnetic radiation.
- Waves models for mechanical waves represent the cycling of the disturbance that creates the wave – e.g., the back-and-forth movement of a speaker creating high- and low-pressure disturbances. Waves models of electromagnetic waves represent the cycling back and forth between the electric fields producing a magnetic field and the magnetic field producing an electric field.
- Electric fields and magnetic fields extend into empty space and since electromagnetic waves are interactions between electric fields and magnetic fields, these waves can travel through empty space including through a vacuum.
- Since mechanical waves are transmitted by matter, they cannot travel through empty space/a vacuum.
- Both mechanical and electromagnetic waves lose energy as they interact with matter through processes such as scattering.
- Waves do not interact with all materials. The wavelength of the wave must be approximately the same size as the object for the wave to interact with the object.
- The process of refraction occurs in both types of waves when the waves cross a boundary between one medium and another.
- Reflection occurs in both types of waves when they meet a surface that does not absorb or transmit the energy of the wave.

Example(s) of Common Student Ideas:

- Mechanical waves can travel through a vacuum.

Revised (2025 Implementation): 8.PS4.2

8.PS4.2 – Construct explanations from observed patterns of wave behaviors to compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission, absorption, and their behavior through a vacuum and/or various media.

PS4.C: Information Technologies and Instrumentation

Guiding Question:

How are instruments that transmit and detect waves used to extend human senses?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to explore how the interactions between waves and matter are applied in different technologies.

CENTRAL IDEA(S)

Visible light is one type of electromagnetic radiation. All types of waves and electromagnetic radiation have properties that limit their usefulness; we cannot see through walls because visible light cannot pass through many solid materials. As humans learn more about the properties of different types of waves, we develop tools that capitalize on the unique properties of different waves to explore our surroundings, and to store and transmit information. There must be understood steps for encoding and decoding messages/information to store or transmit messages and information.

GENERAL PROGRESSION

In elementary school students should have opportunities to design and test systems that encode and decode messages or information. In the early elementary school students look at messages. The idea of information appears in late elementary when students begin to address storing messages or observations. If students design their own systems and processes in elementary school, they are more likely to encounter limits to their system based on their design decisions (e.g., transmitting messages by sound may require quiet surroundings). In middle school students consider how the properties of light have led to different technologies that capitalize on the behaviors of light and sound when they interact with different materials.

K-2 Standards

By the end of grade 2. People use their senses to learn about the world around them. Their eyes detect light, their ears detect sound, and they can feel vibrations by touch.

People also use a variety of devices to communicate (send and receive information) over long distances. – NRC, 2012

Progression Across Grade Bands

This component idea begins as students consider that we use our senses of sight, touch, and hearing to learn about our world and that there we can design ways to communicate over long distances.

A good task for students is to develop a system that sends messages using vibrations, sound, and/or light. They may try to feel taps on a desk, plucks of a string, ripples sent across the surface of water, etc. Students may also develop systems that use sound and light to communicate, such as sequences of claps or turning lights on/off.

It is appropriate for students to realize that there are limits to the solutions that are caused by properties of vibrations, sound, and light. For example, sometimes a sound is too soft to hear, or someone is too far away for us to hear what they're saying. It might be possible to use light to send a message because light can travel further than sound. Strengths and weaknesses are both important.

When students use system models to communicate how their solutions work, then is possible for them to uncover the pattern that the classes' systems all involve some process to encode, transmit, and decode a message. The terms should come after conceptual understanding of the similarities across systems.

The messages that students send in grades K-2 are processed immediately. In later grades students will learn that humans have technologies that store messages. This provides a way to introduce the concept of information – a message that can be stored before it is sent or captured, stored, and retrieved later.

Current (2018 Implementation): 2.PS4.2

2.PS4.2 – Use tools and materials to design and build a device to understand that light and sound travel in waves and can send signals over a distance.

<u>Big Ideas:</u>

We can our senses to send/receive messages using light, sound, or vibrations when the sender and receiver both understand how to encode or decode the message.

(Note: Students are not expected to know that light behaves like a wave, beyond the fact that some objects can produce light and that the light travels outward from the source once it's produced.)

Scientific Ideas:

- Light, sound, and vibrations originate at a source and travel outward from the source in straight lines that we can represent using rays (arrows).
    - We have senses that are able to detect light, sound, and vibrations: our eyes detect light, our ears can hear sounds, and through touch, we can feel vibrations.
- People can create protocols that allow messages to be encoded and decoded. For example, a specific sequence of knocks on the door lets someone monitor who is on the other side without seeing them (e.g., morse code) or raising and lowering certain lights/candles.
- Messages sent using light, sound, and vibrations have benefits and attributes that make them more or less effective under a set of conditions. For example, light can travel further than sound and may be better for sending messages over long distances. However, there must be a way for the receiver to see the light sent by the receiver which may make it difficult to send messages if there are obstacles in the way or if it is bright outside.

Example(s) of Common Student Ideas:

- We can only communicate by sound.

Revised (2025 Implementation): K.PS4.1, 2.PS4.2, 2.PS4.3

K.PS4.1 – Record data from an investigation using senses to detect light, sound, and vibrations and communicate observations.

2.PS4.2 – Use tools and materials to design and build a device to understand that light and sound travel in waves and can send signals over a distance.

2.PS4.3 – Obtain information to describe how devices communicate over a distance using light or sound.

3-5 Standards

Lenses can be used to make eyeglasses, telescopes, or microscopes in order to extend what can be seen. The design of such instruments is based on understanding how the path of light bends at the surface of a lens.

Digitized information (e.g., the pixels of a picture) can be stored for future recovery or transmitted over long distances without significant degradation. High-tech devices, such as computers or cell phones, can receive and decode information—convert it from digitized form to voice—and vice versa.

Progression Across Grade Bands

In earlier grades, students should have seen that humans design systems to send or receive messages that use their senses. As an activity, students may have developed a system to send encoded messages, such as using a blinking light. The behaviors of vibrations, sound, or light caused different solutions to work better under certain conditions. (e.g., it is easier to see light signals at night than during the day). It is likely that students encountered limitations to their systems and explained the cause of the limitations (e.g., messages must be short, messages could only be used when the context was planned ahead of time, it was not possible to ask questions).

In late elementary school students should learn that it is possible to store messages and the idea of storing messages leads students to the concept of "information." Stored messages are one type of information. Digitizing is one way that information can be stored. The process of digitizing builds on the earlier ideas about encoding and decoding messages.

Consider repurposing the K-2 task of designing a system to communicate information that led students to uncover that systems must be able to encode the message. This time, challenge students to create a system to store information. While students may want to think about the objects, they would need to develop in order to store information. If students use system models to communicate their solutions to their peers, they can uncover the pattern that storing information requires a known way to encode and decode the information being stored.

The second strand of this progression is about wave properties and how specific properties affect the way we can use waves. In late elementary students see that the path of light changes when it passes through lenses. Designing devices to improve senses requires that we must understand exactly how light bends when it passes through a lens and not rely on trial and error to make glasses that work properly. If we learn the patterns for how light behaves as it passes through a material, then we can find new ways to use lenses.

In middle school students will learn that the light they have been discussing during elementary school is called visible light and that visible light is part of a larger spectrum of electromagnetic radiation that includes many other types of light. Students will learn that each type of light interacts with matter in unique ways that can be harnessed in the devices we design. This builds directly on notion that learning more about lenses allows us to build new devices using lenses.

Current (2018 Implementation): 4.PS4.3

4.PS4.3 – Investigate how lenses and digital devices like computers or cell phones use waves to extend human senses.

Big Ideas:

Humans design lenses to bend light in specific ways that allow them to magnify or focus light from objects. Other devices can detect things about the physical world and convert that information into a digital format that can be stored or sent.

(Note: Ray diagrams of lenses may help students visualize and understand the way that lenses work, but ray diagrams that show how devices function are beyond the expectations for grade 4.)

Scientific Ideas:

- Light travels in straight lines (represented by arrows). A ray's path changes when it moves across a boundary and into a new medium.
- Every different material has unique optical properties (i.e., the speed that light will travel through them). This causes the path of light to bend at boundaries between one material and another.
- Humans learn patterns for the way that different materials bend light and use these patterns to design lenses for different purposes.
- Some devices use combinations of lenses where each lens alters the path of incoming rays.
- Many communication systems and devices used for communication have protocols. In order to send and receive messages, the source and recipient of the message must both understand the protocol (e.g., saying "over" when you finish talking into a walkie-talkie, sending messages using morse code, storing data for a digital photo).
- Some devices have sensors that gather signals from the physical world and convert the information to a digital format.
- Humans design sensors to collect specific types of information about the surroundings (e.g., temperature, amount of light, humidity, distance from an object, when an object breaks a laser beam). A sensor can only collect the type of information for which it is designed.
- Humans design devices that use sensors to collect information about the physical world and then store or transmit that information using specific protocols.

- Analog signals can be adjusted to infinite points such as, analogous to building with clay, but are easier to distort. Digital signals have limited ranges, analogous to building with Lego blocks, but this makes distortion less of a problem.

Example(s) of Common Student Ideas:

- All signals are digital.

Revised (2025 Implementation): 4.PS4.3

4.PS4.3 – Investigate how lenses enhance human senses and digital devices (e.g., computers and cell phones) use waves to receive and decode information over distances.

6-8 Standards

Appropriately designed technologies (e.g., radio, television, cell phones, wired and wireless computer networks) make it possible to detect and interpret many types of signals that cannot be sensed directly. Designers of such devices must understand both the signal and its interactions with matter.

Many modern communication devices use digitized signals (sent as wave pulses) as a more reliable way to encode and transmit information.

Progression Across Grade Bands:

This progression begins by looking at simple communication systems that use our senses of touch, hearing, and seeing to send/receive messages. In late elementary school students uncover the concept of information as they realize that communication systems can improve when it is possible to store messages either before or after it is transmitted.

Students should have discussed limitations to different types of communication systems depending on whether the systems used vibrations, sound or light to transmit messages. For example, systems of flashing lights that send encoded messages work well at night but could be harder to see during the day. In middle grades students learn about different types of waves and how the properties of these waves are the basis for their use in different technologies. For example, X-ray light (wavelengths from 0.01nm to 10nm) are useful with x-ray machines that can pass through soft tissues but are absorbed by bone.

The topic of encoding and decoding has potentially surfaced twice in earlier grades. First students may have designed systems to encode, transmit, and decode messages. Then in later elementary school students may have addressed encoding and decoding in the context of storing digitized information. In middle grades, students can consider the ways that digitized signals can transmit information. As in earlier grades, there must be a protocol that is known to both the sender and receiver and a medium to transmit the message. The properties of the medium, such as its ability to transmit light are important depending on whether light or sound is used to transmit the signal.

Current (2018 Implementation): 8.PS4.3

8.PS4.3 – Evaluate the role that waves play in different communication systems.

<u>Big Ideas:</u>

Communication systems utilize protocols to transmit digital information, including signals that humans cannot detect with their senses.

Scientific Ideas:

- Waves travel outwards from their source and interact with different objects/materials.
- Mechanical waves (sound and vibrations) can travel through different solids, liquids, and gases, while electromagnetic waves travel through electric and magnetic fields. Since electric and magnetic fields extend into empty space, electromagnetic waves can travel through space.
- Waves transmit energy away from a source and it is possible to design receivers that detect and capture this energy. Since a wave's energy will transfer to its surroundings as it travels from the source to the receiver, it is often necessary to amplify/boost the signal at the receiver.
- To send an encoded message, both the sending and receiving devices must be able to carry out the protocol used to encode/decode the information.
- Humans design devices that use sensors to capture information about their surroundings and store/transfer this information in digital formats. Some sensors are able to detect things that humans cannot detect with their senses (e.g., infrared radiation).
- There are protocols designed to transmit information that has been stored in digital formats. The sender and receiver must use a common protocol in order to send messages.
- Waves interact in different ways with different materials. These differences should be considered depending on the purpose of a designed device.

Example(s) of Common Student Ideas:

- Waves interact the same with all materials/mediums.

Revised (2025 Implementation): 8.PS4.3

8.PS4.3 – Engage in argument from evidence to support the claim that digitized signals, sent as wave pulses, are more reliable than analog signals to transmit information in a system.

LS1.A: Structure and Function

Guiding Questions

How do the structures of organisms enable life's functions?

The Biggest Ideas

PURPOSE

The purpose of this component idea is for students to see that organisms are made of many parts with unique functions and structures that support those functions – from the largest body parts down to the DNA inside of single cells. Each different structure performs a narrow range of tasks. The function of every different part relates directly to its structure.

CENTRAL IDEA(S)

From the smallest particles inside of cells to the body parts of the largest organisms, living things are organized to perform tasks needed to grow, survive, and reproduce. The bodies of large organisms have external parts and organs that specialize in certain tasks. Cells group together in tissues that form specific functions. The inside of cells contains organelles that perform specific functions and even the DNA and other molecules inside of cells are is highly organized. Changes to the shapes of different structures may prevent their typical function.

GENERAL PROGRESSION

Grade Band	Scale	Parts
K-2	Living things big enough to see without a microscope (macroorganisms).	Visible, external parts
3-5	Macroorganisms, microbes (organisms we can only see with a microscope)	Visible, external parts, as well as parts within macroorganisms (e.g., bones and muscles)
6-8	Multicellular organisms, single celled organisms	Internal organization of single and multi-celled organisms.
9-12	Molecular Organ system	Macromolecules and the subunits that affect their function. Interactions among systems

The relationship between structure and function describes how the physical structures of various parts, of living organisms are closely related to their specific functions or roles. This relationship exists at all levels of organization, from the molecular and cellular level up through to the organismal levels. The progression of this component idea moves from looking at entire organisms, down to the contents in cells. Students begin by observing that the bodies of all organisms have visible parts. Later in elementary school students learn that organisms also have internal organization and structures. By middle school, students learn that even the structures within organisms are made of organized tissues consisting of different types of cells. At any level, instruction should focus on relating the shape of structures to the ability of those structures to function in a particular task.

K-2 Standards

By the end of grade 2. All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air. Plants also have different parts (roots, stems, leaves, flowers, fruits) that help them survive, grow, and produce more plants. -NRC, 2012

Progression Across Grade Bands

Students are learning that animals need food and that plants need water and light to live and grow (LS1.C). This component idea is about the different parts of an organism that help them get the things they need. There are three main ideas to connect: organisms have needs, organisms are a collection of parts that perform a narrow range of functions, and each specialized part helps the organism meet its needs. For example, our hands and fingers have many joints that work well for grasping, we use our arms for reaching and the elbow helps us reach things that are close to our bodies as well as extend our arms to reach things that are further away, or the shape of the outer ear that funnels sound towards the inner parts of the ear.

Concrete experiences help students connect structure to function. For example, mittens or popsicle stick finger splints change the structure of the hand. Students can experience how these changes affect their ability to grasp and do simple tasks. Select tasks that specifically connect structure and survival to an organism's needs, such as removing grapes from their stems compared to writing their names. Similarly, splints that prevent students from using their elbows changes change the function of the arms so that they can still reach, but no longer bring food to their mouths. Effective science instruction ensures that students connect these experiences to the ideas of structure and function.

Limit the initial exploration of the structures of organisms to visible, external structures. In later grades, students this component idea will eventually include internal structures that they cannot see and eventually microscopic structures such as cells and even smaller components inside of cells.

Students do not encounter invisible forms of matter until grades 3-5 so discussions about taking in air should focus on breathing through the nose or mouth as a common behavior in many living animals. The ideas of taking in food, water, and air are common experiences that are familiar to students – eating, drinking, and breathing. It is not necessary to talk about the different gases that make up air or any specific purpose for breathing.

Current (2018 Implementation): K.LS1.2, 1.LS1.1, 2.LS1.1, 2.LS1.2

K.LS1.2 – Recognize differences between living organisms and non-living materials and sort them into groups by observable physical attributes.

Big Idea:

All living things get older, get bigger, make new organisms. Among living things, there are features that are common among plants or animals. The respective groups – plants and animals – have common structure that provide a way to sort them.

Scientific Ideas:

- Some things are alive. Other things have never been alive or were once alive but are not alive any longer.
- Living things have bodies with different parts that they use for different activities.
- Living things get larger as they get older.
- Some living things have long lives, others have short lives.
- There are visible, external structures that are common to many different animals.
- There are visible, external structures that are common to many plants.
- It is possible to sort many things into plant or animal groups using visible, external features.

Common Student Ideas:

- All things that are alive can move.
- Things that cannot move around are not alive.
- …

1.LS1.1 – Recognize the structure of plants (roots, stems leaves, flowers, fruits) and describe the function of the parts (taking in water and air, producing food, making new plants).

Big Idea:

Plants, like all living organisms, are made of smaller parts that work together to support the life activities of a plant.

Scientific Ideas:

- Plants are alive and therefore they grow, make new plants, and will eventually die.
- A single plant has different parts and plants use their body parts in different ways.
- The different structures of a plant work together and allow the whole plant to survive and make new plants.
- Plants take in water through their roots and that water can travel to different parts of the plant.

- Different types of plants have different types of roots (e.g., fibrous, adventitious, taproot, foliar) but they all do the same thing.
- Stems of a plant help the plant to stretch towards sunlight and allow water to move from a plant's roots to its leaves.
- There are different types of stems – rigid, flexible. Some grow quickly, others grow slowly.
- A plant uses its leaves to collect sunlight that it needs to grow and to survive.
- Many plants that grow in the same conditions will have similar leaves (e.g., plants growing in very shaded areas often have larger leaves).
- Plants can make new plants, including by making seeds.
- Some plants make flowers that attract pollinators in different ways.
- A flower on a plant only lasts a few days before the flowerhead begins to change.
- If a flower gets pollinated, seeds will develop where plants once had flowers.
- Not all seeds look the same, some seeds drop from old flowerheads, other seeds form inside of fruits or pods.
- Seeds can sprout to make new plants under the right conditions.

Common Student Ideas:

- Plants grow because they absorb food through their roots.
- All plant leaves are the same.
- All plant seeds sprout under the same type of conditions – temperature, light, and water.
- Flowers stay on the plant as long as the plant keeps growing.
- …

2.LS1.1 – Use evidence and observations to explain that many animals use their body parts and senses in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air.

Big Idea:

Organisms have a body (system) that is made up of different external (visible) parts. The organism uses these different parts (system components) to perform the activities of life.

Scientific Ideas:

- Things that are alive have bodies and their bodies have visible body parts.
- Animals use their body parts in different ways.
- Organisms with similar body parts often use those body parts to accomplish tasks that are similar.
- Living things will grow, they must have a way to take in "food."
- Different animals use the parts of their body for different tasks.

- Many different animals have body parts that look similar, and the animals use in a similar manner.
- Typical uses for animal parts include seeing hearing, grasping, protection, locomotion (moving from place to place).
- An organism uses a collection of its parts to seek, find, and take in food and water.

Common Student Ideas:

- Limbs are only for moving from one place to another.
- …

2.LS1.2 – Obtain and communicate information to classify animals (vertebrates- mammals, birds, amphibians, reptiles, fish, invertebrates – insects) based on their physical characteristics.

Big Idea:

There are many different types of animals that can be sorted into groups by looking at their different parts.

Scientific Ideas:

- Animals have bodies and their bodies have different visible parts.
- Many different types of animals have body parts that look similar and similar- looking parts are often used in similar ways (e.g., many animals have legs they use to move).
- Animals may have parts that are more unique (e.g., some have fins, skin, or hard shells).
- Animals can be placed into groups with other animals that have body parts that are alike.
- It is often possible to divide a group of like animals into even smaller groups by looking for other similarities and differences.

Common Student Ideas:

- All animals have skin and hair/fur.
- …

Revised (2025 Implementation): 1.LS1.1, 2.LS1.1, 2.LS2.1 (typo in standard by component table in standards?)

1.LS1.1 – Develop and use a model to explain the structure of plants (i.e., roots, stems, leaves, flowers, fruits) and describe the function of the parts (taking in water and air, producing food, making new plants).

2.LS1.1 – Use evidence and observations to explain that many animals use their body parts and senses in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air.

2.LS1.2 – Obtain and communicate information to classify animals (i.e., vertebrates: mammals, birds, amphibians, reptiles, fish; and invertebrates: insects) based on their physical characteristics.

3-5 Standards

By the end of grade 5. Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. (Boundary: Stress at this grade level is on understanding the macroscale systems and their function, not microscopic processes.) – NRC, 2012

Progression Across Grade Bands

Students looked at the structure and function of external parts of plants and animals in earlier grades. At that time there was a very limited set of needs for living things to grow – plants need light and water and animals need food. Students explored how the shape of external parts of organisms supports tasks that help plants and animals grow and stay alive.

There are two developments in grades 3-5 which that affect this component idea. The first development is learning that there are invisible forms of matter. Students have already discussed that living things breathe in earlier grades. At that time there was no attempt to explain why. Now that students understand that air is made of particles, it is possible for students to understand that breathing is a way that living things take in air particles. The second development is that there can be unseen layers of organization. This allows students to consider that living things have internal structures. These internal structures perform a limited set of tasks just like external structures students studied in earlier grades. For example – organisms have lungs where air particles move to and from as they breathe in and out.

Instruction should focus on internal structures that are related to grade-appropriate functions. For example, it is reasonable to talk about the windpipe/trachea that connects the mouth and nose to the lungs and allows air particles to move from outside the body into the lungs. Using grade-appropriate structures also allows students to see how changes to these structures will impede their function. For example, narrowing or obstructing the windpipe prevents air from reaching the lungs.

Current (2018 Implementation): 3.LS1.1

3.LS1.1 – Analyze the internal and external structures that aquatic and land animals and plants have to support survival, growth, behavior, and reproduction.

Big Ideas:

Organisms are a large system that contains subsystems of organs that interact to keep the organism alive. *[Clarification: Focus should be on large processes, not microscopic processes.]*

Organisms have internal structures and organization and like the external parts explored in earlier grades, these structures interact and support life functions. *[Boundary: This standard does not attempt to establish a representative species but intends for students to explore the variety of ways that individual organisms achieve a common set of activities.]*

Scientific Ideas:

- There is a wide variety of life on earth, but all organisms carry out the same general activities: survival, growth, behavior, and reproducingreproduction.
- Survival (grades 3-5) refers to the act of meeting physical needs: food, water, air, shelter, and safety.
- An organism must take in matter to grow – food for animals, gases from the air for plants.
- A key feature to of life is havingbeing young. Living organisms engage in behaviors that attract mates. *[Boundary: Activities of sexual reproduction and associated organ systems are not intended for grade 3 students.]*
- There are patterns in the way that organisms of the same type behave, and organisms use different external parts as part of these behaviors.
- Multiple structures and organs work as a system to accomplish a variety of macroscopic processes (e.g., breathing).
- Because organ systems depend on each other, an organism does not survive if one of its systems fails.
- There are physical connections between the organs in a system and across different systems.
- There is a pattern in the needs of organisms (e.g., all must take in matter to grow) but there are many successful variations to in the way that life meets these needs.

Common Student Ideas:

- The "guts" or inside of an organism are an unorganized mess.
- Each system in an organism is isolated from the other systems.
- …

Revised (2025 Implementation): 3.LS1.2

3.LS1.2 – Analyze the internal and external structures that aquatic and land animals and plants have to support survival, growth, behavior, and reproduction.

6-8 Standards

By the end of grade 8. All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular). Unicellular organisms (microorganisms), like multicellular organisms, need food, water, a way to dispose of waste, and an environment in which they can live.

Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues or organs that are specialized for particular body functions. (Boundary: At this grade level, only a few major cell structures should be introduced.) – NRC, 2012

Progression Across Grade Bands

The idea that all living things are made of cells and that all matter is made from a limited set of different types of atoms shapes the middle grades progression for this component idea.

The structures covered in this component idea have gotten progressively smaller through grade bands. First students considered only external parts of living things and how the structure of these parts contributed to their function. Then students learned that organisms have internal structures that help them get the bulk materials (e.g., food, water, air) they need to support growing and staying alive in earlier grades. The idea of internal organization progresses in this component idea as students learn that the structures they learned about in earlier grades are organized still further into tissues composed of different types of cells.

Students learn that some materials get used by living things and must be constantly replenished, but other materials accumulate and must be removed from our bodies. As students learn that "bodies" as collections of cells, they can understand that all of those cells must have a way to receive the materials they use and ways to get rid of the materials that accumulate.

For example, students learn that "air" is really a collection of specific gases, such as carbon dioxide and oxygen gas. Cells far away from the lungs must be able to get oxygen and to get rid of carbon dioxide. Students learn that different types of cells exist as tissues that make up structures such as the lungs, blood vessels, and/or blood that each perform a specific function to allow cells to exchange carbon dioxide and oxygen.

The idea of function being affected by structure also appears on a new scale. Students can consider how certain tissue types are necessary in order for the different larger structures to function. For example, this could include how arrangements of tissues in the lungs permit gas exchange. *(Note: Middle school students are not expected to understand the differences between cell types that contribute to their unique functions.)*

Current (2018 Implementation): 7.LS1.1, 7.LS1.2, 7.LS1.3, 7.LS1.4, 7.LS1.5

7.LS1.1 – Develop and construct models that identify and explain the structure and function of major cell organelles as they contribute to the life activities of the cell and organism.

Big Idea(s):

Individual cells in multicellular and unicellular organisms are a complete system made up of smaller components that carry out the activities required to sustain life. *[Boundary: Organelles in this grade band are intended to be those involved with basic life- supporting functions, excluding those whose primary role is in protein synthesis.]*

Scientific Ideas:

- A cell is the smallest unit of life that has the same needs as a larger organism: obtain food and water, dispose of wastes, and create a suitable environment for living.
- There are whole organisms that are only one cell in size.
- Larger organisms are made up of many individual cells.
- A single cell is a complete system that has internal structures that organize the activities of life – these internal structures are called organelles.
- Each organelle has a specialized function.
- Specialization of roles in a cell makes the cell more efficient.
- Organelles have membranes that retain certain chemicals within the organelle. The effect is to increase the rates of reactions by concentrating certain reactants in a smaller space. For example, different enzymes needed to copy DNA are concentrated inside the nucleus where they are more likely to interact with the DNA itself.
- Mitochondria in plants and animals rearrange the atoms in certain types of matter which releases energy.
- Chloroplasts found in plants capture energy from light and produce sugar from carbon dioxide and water.
- The nucleus contains chromosomes that contain genes.
- Lysosomes allow cells to remove waste from the inside of a cell.
- Vacuoles store materials and may have specialized roles such as central vacuoles in plants or contractile vacuoles in paramecium which help maintain a stable environment inside the cell.

Common Student Ideas:

- All animal cells are the same as each other.
- The cells in an organism are all the same as each other.
- …

7.LS1.2 – Conduct and investigation to demonstrate how the cell membrane maintains homeostasis through the process of passive transport.

Big Idea(s):

The structure of the cell membrane allows some materials to pass through it which provides some control over the things that enter and leave a cell. [*Boundary: Facilitated diffusion exceeds the expectations of this standard*.]

Scientific Ideas:

- A membrane is a thin material that can physically separate two spaces.
- All cells have a cell membrane that acts as a boundary between the cell and its surrounding environment.
- The basic structure of the cell membrane is the same in all organisms and organelles. [*Boundary: Students are not expected to know the structure of the membrane or be familiar with the fluid mosaic model of the membrane at this level*.]
- Some materials can pass through the cell membrane, but other materials are not able to pass through the cell membrane. [*Boundary: Diffusion is limited to the transport of carbon dioxide, water, and oxygen*.]
- Between cells there is an area of non-living fluid. Different tissues have different amounts of space and fluid between cells.
- The fluid between cells contains water and many different dissolved materials.
- The amount of a dissolved material in the fluid outside of cells changes based on inputs/outputs into the body system.
- Water can move in or out of cells, as well as some gases: oxygen and carbon dioxide.
- Water and gases move randomly inside of a cell and in the space outside of the cell.
- Water and gases that are taken in through the respiratory and digestive system, or produced by cells accumulate in certain regions. These regions where the materials accumulate are described as having high concentrations when there are greater amounts of those materials relative to the areas that surround them.
- When two adjacent areas, separated by a semipermeable membrane, contain different concentrations of dissolved materials, then then the random motion of particles will eventually result in an even distribution of the materials those that are able tocan move across the membrane.
- The movement of particles across the membrane will continue even at equilibrium.

Common Student Ideas:

- The cell membrane chooses materials that are allowed to enter the cell.

- There is no space between cells in a tissue.
- Materials line up outside of the cell membrane to gain entrance between the cells.
- …

7.LS1.3 – Evaluate evidence that cells have structural similarities and differences across kingdoms.

Big Idea(s):

All living things are made up of cells and the smallest living things are made of only one cell.

Even though organisms look very different from each other, multicellular organisms are extremely similar at the scale of a single cell, and the similarities persist even when compared with unicellular organisms.

[*Boundary: The intent of this standard is not to debate the appropriateness of the idea of kingdoms with respect to ancestry, but to note similarities and differences across different forms of life.]*

Scientific Ideas:

- An individual cell is a complete system and part of other systems. These other systems may be a system of other cells in a multicellular organism and always part of an ecosystem.
- Within cells, there are parts that harvest the energy stored in sugars.
- There are also parts that connect amino acids together to create the proteins that carry out life's functions.
- Plant and animal cells have many structures in common, but plants possess structures that allow them to convert light energy into chemical energy and convert carbon into forms that can be received and stored by other organisms.
- Single- celled organisms have the same needs as multicellular organisms – need food, water, air, a way to dispose of waste, and an environment to live in.
- Plant cells have cell walls.
- Most cells are composed of only a small number of chemical elements: carbon, hydrogen, nitrogen, oxygen, phosphorous, and sulfur.

Common Student Ideas:

- Single- celled organisms don't have smaller parts inside them.
- Single- celled organisms don't have the same needs as multicellular organisms.
- …

7.LS1.4 – Diagram the hierarchical organization of multicellular organisms from cells to organism.

Big Idea(s):

A pattern exists in multicellular organisms where cells are organized into tissues which may further be organized into organs and systems of organisms.

Scientific Ideas:

- Cells are the smallest unit of life.
- Cells in organs work together to meet the basic needs of all cells.
- Organization and specialization increase the efficiency of the reactions that sustain life. Organs and organelles both utilize this strategy.
- Groups of similar cells have specialized roles in tissues.
- Organs are collections of at least two different types of tissues that interact to perform a specific function.
- An organ system is a collection of organs.
- Organ systems interact with each other and depend on each other.
- The cells in a multicellular organism all come from a single cell, but as they divide, the cells respond to external signals, express different genes, and because of the different sets of proteins they perform different roles.

Common Student Ideas:

- Organs are made up of only one type of tissue.
- Organ systems are isolated from each other.
- …

7.LS1.5 - Explain that the body is a system comprised of subsystems that maintain equilibrium and support life through digestion, respiration, excretion, circulation, sensation (nervous and integumentary), and locomotion (musculoskeletal).

Big Idea(s):

In multicellular organisms, there are systems of connected structures that perform a narrow range of functions. Each system is a collection of specialized structures, each with a limited range of functions.

Scientific Ideas:

- The human body is a complete system that contains a number of sub-systems.
- The human body takes in food, which provides the building materials (matter) for growth.
- Food, in combination with oxygen provides the human body with energy.
- The respiratory system includes the lungs where oxygen needed to release the energy from food enters the body and releases the carbon dioxide that is released as the food is broken down.

- Processes that yield energy from food produce both solid wastes and dissolved wastes. These materials are removed by the large intestine (solids) and urinary tract (dissolved materials).
- The body is at a consistent temperature even though the reactions that harvest energy from food also release heat energy. The skin and lungs release energy to maintain temperatures that are ideal for the reactions occurring in the body.
- The nervous system and its interaction with the surroundings through the senses allows the allow human beings to learn and adjust their activities/behavior according to their surroundings.
- The reactions in the body occur in an environment with abundant water. The skin prevents us from losing water to our surroundings.

Common Student Ideas:

- Organ systems have only one function and do not interact with other systems.
- …

Revised (2025 Implementation): 7.LS1.1, 7.LS1.2, 7.LS1.3

7.LS1.1 - Develop models that identify and explain the structure and function of major cell organelles and structures (i.e., vacuoles, chloroplasts, lysosomes, mitochondria, cell membrane, cell wall, nucleus, cytoplasm) as they contribute to the life activities within a system.

7.LS1.2 - Obtain information about the cellular structures of unicellular and multicellular organisms across kingdoms and domains in order to compare how these structures support the functions (i.e., obtain food, water, waste disposal, and the environment in which they live) of the organism.

7.LS1.3 - Develop and use a hierarchical model of a multicellular organism to explain that the body of humans and other animals is a system of multiple interacting subsystems specialized for particular body functions [e.g., digestion, respiration, excretion, circulation, sensation (nervous and integumentary), locomotion (musculoskeletal), reproduction, and immunity].

9-12 Standards

Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules, such as water, proteins, carbohydrates, lipids, and nucleic acids. All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.

Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Outside that range (e.g., at a too- high or too- low external temperature, with too little food or water available), the organism cannot survive. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system. – NRC, 2012

Progression Across Grade Bands

This progression includes three large ideas that emerge in high school.

1. Cells are organized and have internal components. The structure of these parts increases the efficiency of the unique reactions that occur within each part.
2. Genes are highly organized sections of DNA where sections of the sequence (parts) play a role in regulating gene expression and thus the development of organisms.
3. Living things are a collection of chemical reactions and organisms have systems that maintain optimal conditions for these reactions to occur.

At all levels, living things are highly organized. Specialized parts perform a limited ranges of tasks that help an organism survive. The structure of each part is suited to its specific function. In early elementary, students begin this progression by considering the large, external parts or organisms (e.g., elbows, ears) and how their structure is suited to their function. Internal parts of organisms, such as bones and organs, are added in intermediate grades. In middle school, students learn that organs are smaller parts of larger systems. The larger system and smaller components each have specialized functions and are organized in ways optimized for these functions, including different types of cells organized into tissues. The trend of exploring smaller and smaller parts continues in high school where students learn that cells contain internal parts with specialized roles.

In earlier grades, students learned that survival depends on getting food, water, and air. By middle school, students begin to understand that food provides both matter and energy needed to survive. In high school, students should understand that to "stay alive" means that an organism must sustain a collection of chemical reactions between a variety of molecules. These chemical reactions produce proteins, permit growth through cell division, etc. Cells are a system with internal components. The internal parts of cells have unique structures that increases the efficiency of specific sets of reactions that occur within each part.

Students should reach high school with an understanding that inheritance explains why there are similarities between parents and their offspring. In middle school, students learn that chromosomes contain genes from both parents and that the transfer of these genes from parent to offspring is the mechanism for inheritance. Students have not learned specifically about DNA, nor that genes are also organized. It is important for students to understand that all cells contain all genes and that the expression of different parts of these genes explains the variety of cells that arise as the cells in multicellular organisms divide and differentiate.

In intermediate grades students learned that there are factors that affect how quickly solids dissolve.In intermediate grades, students learned that factors affect how quickly solids dissolve. Students were introduced to chemical reactions in the middle grades. These concepts are a likely starting point for students with less chemistry background to understand that conditions such as temperature affect how quickly life- sustaining reactions occur in living organisms. Organisms have mechanisms that serve to keep their bodies within a range of conditions that are ideal for the reactions that occur within their cells and bodies.

Revised (2025 Implementation): Bio1.LS1.1, Bio1.LS1.2

Bio1.LS1.1 – Construct an explanation based on evidence that the essential functions of life are primarily carried out through the work of proteins that are coded for by genes in DNA, as described by the Central Dogma (i.e., transcription, translation).

Big Idea(s):

Genes are organized sequences of DNA that include regions with specific functions. The expression of coding regions of DNA produces proteins through the processes of transcription and translation.

(overlap with LS3.A endpoints)

Scientific Ideas:

Proteins:

- Most of the macroscopic features and processes of living things depend on interactions between proteins at the sub-cellular scale. Various conditions and disorders arise in cells/organisms that are unable to produce proteins, produce too much of a protein, or produce altered forms of a protein.
- Each different type of organismsorganism produces a unique set of proteins. Even in organisms of the same type, there can be variation in the expression of proteins.
- Proteins are particles made in cells that are smaller than cells. They exist inside cells, embedded in other cell parts, or outside of cells in multicellular organisms.
- Proteins are not able to move on their own. Some proteins are attached to each other or to cell parts and therefore they remain in one place. Other proteins are unattached and drift freely in fluids.
- Proteins cannot drift freely across cellular membranes, but cells have mechanisms to move proteins in or out.
- The appearance and metabolic activities of living things can be traced back to chemical reactions involving proteins.
- Proteins perform a variety of roles in which they interact with different compounds, such as other proteins, sections of DNA, materials such as carbohydrates that are consumed by organisms, etc.
- When a protein interacts with another compound, the shape of the protein changes. Shape changes can enable further reactions. In other cases, shape changes prevent further reactions. These shape changes allow proteins to be involved with a variety of feedback mechanisms.
- It is possible for a protein to take an irregular shape, either during and or even after its it is produced.

<u>DNA, Chromosomes, and Genes:</u>

- All living things contain cells with DNA. In multicellular organisms, the DNA can take the form of a chromosome – a nucleic acid molecule made of a very long chain of nucleotides.
- Nucleotides are incredibly small pieces that make up a molecule of DNA. This molecule is not visible, even with a microscope, except when the chain wraps/bundles up tightly.
- Then entire nucleotide chain is made of four different nucleotides – adenine, thymine, guanine, and cytosine. Adenine and thymine nucleotides occur in equal amounts, and the nucleotides guanine and cytosine occur in equal amounts.
- Each chromosome is organized and has sections of nucleotides called genes. There are many genes on a single chromosome.
- Each gene is organized into sections of nucleotides with specific functions: a promoter region of nucleotides where RNA polymerase bonds, sequences of nucleotides that can block or allow RNA polymerase, a coding region that is transcribed to make a mRNA molecule, and a termination sequence that stops the transcription of the mRNA.

<u>Genes to Proteins</u>

- The major tasks involved in producing a protein from the information encoded in a gene are transcription and translation.

- During the process of transcription, an enzyme called RNA polymerase creates an RNA copy of one strand of DNA. This copy is called mRNA.
- Transcription occurs in the nucleus and results in the creation of an RNA copy of the gene that can travel out of the nucleus.
- The promoter region of the gene is the place where transcription starts. There are molecules that can attach to the points along the DNA strand and prevent the RNA polymerase from making an RNA copy of the gene.
- Each gene contains a coding region. The coding region contains the sequence of nucleotides that are copied to make a molecule of RNA.
- Translation occurs at ribosomes outside of the nucleus. This is a metabolic process where sets of 3 nucleotides correspond with a specific amino acid.
- As the ribosome processes the mRNA strand, three nucleotides at a time, a growing chain of amino acids forms. This chain of amino acids is one of many proteins that carry out the essential functions of life at the molecular level.

Common Student Ideas:

- We get the proteins we need from the food we eat.
- Cells only contain the genes for the proteins they need.

Bio1.LS1.2 – Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

Big Idea(s):

Organisms survive in a variety of external conditions because they have feedback mechanisms which that maintain relatively stable internal conditions.

Scientific Ideas:

- Living things depend on a variety of metabolic pathways (sequences of chemical reactions).
- These reactions and the associated molecules depend on certain internal conditions.
- Feedback mechanisms at various scales to maintain an optimal range of conditions.
- Organisms possess feedback mechanisms to maintain consistent: temperatures, pH (acid-base levels), water balance, nutrient levels, pH, ion concentrations, blood pressure, blood glucose levels, waste removal, etc.
- A feedback loop happens when the presence of one thing causes a change in a pathway.
- A negative feedback mechanism in a pathway will slow down or turn off a pathway.
- A positive feedback mechanism in a pathway will cause the pathway to increase its output.
- Organisms have feedback loops at multiple scales – gene regulation, cell activities, and interactions between organ systems.

Common Student Ideas:

Homeostasis is the same thing as chemical equilibrium.

LS1.B: Growth and Development of Organisms

Guiding Question

How do organisms grow and develop?

The Biggest Ideas

Purpose

The purpose of this component idea is for students to see that each different type of living things progresses through typical changes as they get develop and get older. This includes changes in structure and behavior.

Central Idea(s)

All living things progress through developmental stages as part of their life cycle. Each species has a unique life cycle. Developmental stages are marked by changes in the appearance and behaviors of the organisms. Organisms grow as their cells divide. When living things do not have access to resources (social and/or material), they may not grow and develop in a way that is typical for their species. Reproducing is one part of a species' life cycle. A species can become extinct if it does not reproduce fast enough to replace organisms that die off.

General Progression

Grade Band	Development
K-2	Patterns in the ways that plants and animals grow and change throughout their lifetime.
3-5	Life cycles of plants and animals including having young.
6-8	Genetic and environmental factors that influence the growth and reproductive success of plants and animals.
9-12	Multicellular organisms grow and develop as a result of cellular reproduction and differentiation.

Students begin this progression by observing that all members of a particular species will undergo similar changes in appearance at approximately the same age. These observations lead to a discussion of life cycles. Students learn that reproduction is essential for the survival of each species since the life cycle of all living things eventually includes death. In the middle grades, students learn about cells which allow allows them to understand that an organism grows because their cells divide.

K-2 Standards

By the end of grade 2. Plants and animals have predictable characteristics at different stages of development. Plants and animals grow and change. Adult plants and animals can have young. In many kinds of animals, parents and the offspring themselves engage in behaviors that help the offspring to survive.
– NRC, 2012

Progression Across Grade Bands

All living things progress through a sequence of developmental stages – these stages are marked by changes in the appearance and the behavior of the organism and are typical for each type of organism.

Early elementary students should be able to identify and describe obvious physical changes. The intent is for students to see that a group of organisms change in the same way, rather than just looking at one organism. For example, noticing that very young deer all have spots until their first winter. It is not necessary to focus on specific terms found in different stages – e.g., chrysalis, dicotyledon, etc. However, it may be helpful to introduce these terms after students have used everyday language to describe changes they see.

Part of this progression is understanding that living things also develop through behavioral stages. Models such as Erikson's Model for human development describe features for different stages;, however, these changes are too abstract for young students. It is possible for students to observe the behaviors of parents and their offspring. Students may understand that behaviors such as nursing or egg sitting help offspring survive and also that these behaviors are temporary. In later grades, students will learn that there are other behavioral stages for organisms that are less visible.

Current (2018 Implementation): 1.LS1.2, 2.LS1.3

1.LS1.2 – Illustrate and summarize the life cycle of plants.

Big Idea:

Plants progress through common stages of development.

(*Note: Life cycle refers to specific stages that a plant progresses through but should focus on a single generation.)*

Scientific Ideas:

- All seeds contain material that can become a new plant.

- When exposed to certain conditions of light and temperature, the plant within a seed can begin to grow.
- Different seeds require different amounts of time and different conditions to sprout (e.g., some seeds must experience weeks of cold temperatures before they will sprout).
- Young seedlings will have either one or two leaves. If these leaves are removed (the stem is cut) the plant will not survive. Plants of the same type will have the same number of leaves when they sprout.
- As a plant grows, its stem will get longer as the plant moves towards light.
- Different types of plants grow at different rates, under different conditions (e.g., temperature), and to different heights, but plants of the same type will usually grow at similar rates and to similar heights as long as they are growing in similar conditions.
- Plants will continue to produce more leaves as they grow older.
- Flowering plants will grow up and produce flowers.
- Different types of plants produce flowers at different times of the year, but plants of the same type will typically produce flowers at the same time.
- Flowers may look very different from each other but have similar features [*Boundary: Students are not responsible for memorizing flower anatomy. The intent is to allow students to observe that many flowers are similar even when they come from very different plants*.]
- Flowers will fade and turn brown, but if they have been pollinated, then part of the flower will begin to swell and eventually produce seeds and may also produce a fruit that contains the seeds.
- New plants can be grown from collected seeds and these new plants will develop through the same stages and look similar to the plants that produced the original fruit from which the seeds were collected.

<u>Common Student Ideas:</u>

- Seeds are not alive.
- Young plants look like smaller versions of grown-up plants.
- All plants have flowers.
- All flowering plants all make flowers in the spring.
- …

2.LS1.3 – Use graphical representations to show that species have unique and diverse life cycles.

<u>Big Idea:</u>

Each type of organism has a life cycle that consists of typical changes in the appearance of the organism.

<u>Scientific Ideas:</u>

- Life cycles include distinct phases – being born (seeds sprouting in plants) and growing.
- Growing includes both getting older and getting bigger.
- Organisms that are the same type will experience the same changes to in appearance at approximately the same age. For example, the spots on a young deer are not present in their second spring of life.
- The appearance of some organisms changes very little over their lifetime, while other organisms look very different at different stages of their life.
- Changes to appearance may happen early and quickly in some types of organisms, while other types of organisms may change slowly.
- Adult plants and animals can have young.
- Different types of organisms are alive for different amounts of time.

Common Student Ideas:

- Organisms, like butterflies, are a different organisms when they emerge after a significant change in their appearance.
- …

Revised (2025 Implementation): 1.LS1.2, 2.LS1.3

1.LS1.2 – Observe and analyze how living organisms grow and change over time.

2.LS1.3 – Identify ways in which some animals, both parents and offspring, participate in behaviors that help the offspring survive.

3-5 Standards

By the end of grade 5. Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles that include being born (sprouting in plants), growing, developing into adults, reproducing, and eventually dying. – NRC, 2012

Progression Across Grade Bands

Students have seen that organisms undergo characteristic changes in appearance at approximately the same age and that there are behaviors that are only seen at certain times in an organism's life.

As students explore the concept of life cycles, the pair of ideas that show up in this grade band are death and reproduction. These ideas are complimentarycomplementary. Students learn that death is an inevitable point in the life cycle of all living things, and this means that reproduction is essential. Threatened and endangered species are one way to explore these ideas. Programs to save endangered species are only possible when the remaining members of a species are able to reproduce. When reproduction is no longer possible, extinction is inevitable.

In later grades, students will consider ways that organisms engage in behaviors that make it more likely that they will reproduce.

Current (2018 Implementation): Covered in earlier grades – 2.LS1.3

Revised (2025 Implementation): 3.LS1.1

3.LS1.1 – Use graphical representations to compare how species including humans and other organisms have unique and diverse life cycles.

6-8 Standards

By the end of grade 8. Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. Animals engage in characteristic behaviors that increase the odds of reproduction. Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features (such as attractively colored flowers) for reproduction. Plant growth can continue throughout the plant's life through production of plant matter in photosynthesis. Genetic factors as well as local conditions affect the size of the adult plant. The growth of an animal is controlled by genetic factors, food intake, and interactions with other organisms, and each species has a typical adult size range. (Boundary: Reproduction is not treated in any detail here; for more specifics about grade level, see LS3.A.) – NRC, 2012

Progression across grades:

Students have discussed that life cycles include changes in the appearance of organisms that happen at typical points as well as the idea that a species can only exist over time if members of that species are able to reproduce. Now that the necessity of reproduction has been established, middle- grade standards explore ways (e.g., behaviors and structures) that organisms increase the probability that individuals will reproduce.

In middle school, students learn about cells. Students already know that organisms need things like food and water to survive. Learning about cells provides a way for students to understand how whole organisms grow as their cells divide. Students may have developed ideas about how growth occurs without incorporating cells into their mental models. It is important that students have opportunities to make their models for the growth of organisms visible and incorporate new elements such as tissues and cells into these models.

A developing understanding that genes determine the appearance of an organism allows students to begin to understand why organisms of the same type have similar development as well as factors that can lead to differences in the growth of individuals.

Current (2018 Implementation): 7.LS1.6, 7.LS1.7, 7.LS1.8

7.LS1.6 – Develop an argument based on empirical evidence and scientific reasoning to explain how behavioral and structural adaptations in animals and plants affect the probability of survival and reproductive success.

Big Idea:

Animals engage in characteristic behaviors that increase the odds of reproduction. Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction.

Scientific Ideas:

- A part of the life cycle of all organisms is to reproduce.
- Because individual organisms eventually die, a species will become extinct if individuals do not reproduce.
- There are similarities in the way that plants and animals combine genetic information from parents to produce offspring.
- Plants and animals have features that increase the likelihood that they will find a mate or pass on reproductive cells. *(Boundary: This standard does not intend to discuss structures that address reproductive organs in animals.)*
- Every species has a range of behaviors that are unique and contribute to their success in reproducing.
- Advantageous behaviors may not initially be common in a species, but over time successful reproduction by organisms employing the behaviors make the behaviors more common.

Common Student Ideas:

- A plant will die if a pollinator does not visit the plant.
- …

7.LS1.7 – Evaluate and communicate evidence that compares and contrasts the advantages and disadvantages of sexual and asexual reproduction.

Big Idea:

When organisms reproduce, the offspring that they produce contain genetic information that comes from the parent generation and is the same as the parent's genetic information to varying degrees.

Scientific Ideas:

- Genes are segments of chromosomes that create instructions for how to make a certain protein.
- Generally, people have two copies of every gene. One copy on each of a "pair" of chromosomes.
- The proteins made using instructions (genes) found on chromosomes carry out cellular activities that determine how a cell or organism behaves or appears.
- In both sexual and asexual reproduction, organisms transfer genetic information to their offspring by transferring chromosomes.

- In asexual reproduction, organisms receive chromosomes that are both complete and identical to their parents and their offspring, and therefore parent and offspring have identical sets of genes.
- Ignoring the effects of the environment, asexual reproduction will create offspring with characteristics that are exactly like their parents.
- In sexual reproduction, each parent makes a special reproductive cell that contains only one copy of each gene. This is half as much DNA as every other cell in their body.
- In sexual reproduction, two special reproductive cells combine.
- Each reproductive cell involved in sexual reproduction carries half of the genes of the parents.
- Sexual reproduction will create offspring that look similar to either parent, but not will not be identical to either parent.
- Genetic variation describes the amount of similarity or difference in the genes in a group of the same type of organisms. When a group of the same type of organisms have has very similar genes, the group is described as having low variation.
- A disturbance that affects a group of organisms that reproduces asexually can have a very significant impact on the group because there is so little variation in the group.
- In a group of the same type of organisms that reproduce asexually, there will be more variation (individuals will have combinations of genes that are not alike). Individual organisms will experience the disturbance to different degrees, but as a group, the effect of the disturbance will be less severe.
- Sexual reproduction requires that organisms spend energy engaging in behaviors that help them find a mate.
- Asexual reproduction allows cells/organisms to reproduce without spending energy searching for a mate.

Common Student Ideas:

- Sexual and asexual reproduction result in organisms that are both like the parent generation to equal extents.
- Sexual reproduction refers only to organisms that engage in sexual intercourse in a manner that is similar to human beings.
- ...

7.LS1.8 – Construct an explanation demonstrating that the function of mitosis for multicellular organisms is for growth and repair through the production of genetically identical daughter cells.

Big Idea:

In order to grow, or produce cells to replace damaged cells, a mechanism exists that creates cells that are identical to the lost cells.

Scientific Ideas:

- An organism grows by taking in matter and using that matter to produce new cells.
- An organism is made nearly entirely of cells. If all the cells of an organism are removed, there would only be a few sorts of proteins, ingested food, and fluids remaining.
- All new cells in an organism come from existing cells.
- Tissues heal because cells divide and new cells replace existing, removed, or injured cells.
- Organisms grow by making more cells.
- When a cell divides, both resulting cells obtain a complete, duplicate copy of the organism's entire genetic information.
- There is a pattern in the events that occur when cells divide, and this pattern is the same in many different types of cells and organisms.
- All cells in an organism are very similar but behave differently because they produce different proteins.
- In a multicellular organism, cells receive signals from neighboring cells and their environment that determine which proteins they will produce.
- The genetic information of an organism is found within all the cells of that organism.

Common Student Ideas:

- Eating food is ONLY so that we have energy.
- Organisms grow as their cells get larger.
- When an organism is injured, the injury heals as cells reattach to each other.
- Cells are too small to be injured.
- …

Revised (2025 Implementation): 7.LS1.4, 7.LS1.6

7.LS1.4 – Analyze data to determine the effect of genetic factors (e.g., specific breeds of organisms and their typical sizes) and environmental factors (e.g., food and space availability) that influence the growth of plants and animals.

7.LS1.6 – Develop and use a model (e.g., Punnett squares, diagrams, and simulations) as evidence to demonstrate why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

9-12 Standards

In multicellular organisms, individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. As successive subdivisions of an embryo's cells occur, programmed genetic instructions and small differences in their immediate environments activate or inactivate different genes, which cause the cells to develop differently—a process called differentiation. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. In sexual reproduction, a specialized type of cell division called meiosis occurs that results in the production of sex cells, such as gametes in animals (sperm and eggs), which contain only one member from each chromosome pair in the parent cell.

– NRC, 2012

Progression Across Grade Bands

There are two key ideas in the high school standards about the growth and development of organisms.

1. Cell division, which explains how a single cell can divide to produce such a great quantity of cells in an adult organism through mitosis.
2. Cell differentiation, which explains how a single cell can divide to become such a great diversity of cells in an adult organism through gene regulation and expression.

The highly organized structure of living things arises out of repeated cell divisions, starting from a single cell. In all grade bands, this component idea helps students understand that life develops in stages. Thinking of development in stages begins with individual organisms and observing patterns in organisms of the same type at certain points in their lives. Students might observe that all chickens hatch from eggs and are born with soft feathers that are different from their adult feathers. In plants, students may observe that the first leaves of many plants occur as a pair or that fruits only develop after plants flower. In the intermediate grades, students consider life cycles, observing that there are patterns across all living things that include being born, growing, reproducing, and eventually dying. Discussions of life cycles overlap with early discussions of inheritance where students observe that organisms have features that are like their parents.

The focus of middle school standards relating to growth and development is on reproduction and the interplay of genes and environmental factors on growth. Middle school students discuss the gene as a unit of inheritance that passes from parent to offspring. The transfer of this unit of inheritance explains similarities in the characteristics of parents and offspring. Component idea LS1.B introduces specialized reproductive cells that can explain how genes transfer to offspring and how new combinations of genes emerge in offspring – there is no explicit discussion of the mechanism of sexual reproduction or the formation of reproductive cells. As middle school students learn about specific elements and different forms of energy, they are able to consider that growth is a combination of both genetic and environmental factors. As middle school students learn about specific elements and different forms of energy, they can consider that growth is a combination of genetic and environmental factors.

In high school, students return to the idea that growth occurs in stages. The scale of these discussions is smaller. Students consider how organisms develop from a single cell through cell differentiation and the stages of cellular division during mitosis. The focus of discussions of mitosis should be on the mechanism that leads to subsequent cells with a complete copy of the organism's genes. When students understand that all cells contain a full copy of the gene, they are prepared to understand the way that turning on and off certain genes can lead to such a variety of cells and tissues in a fully developed organism.

Revised (2025 Implementation): Bio1.LS1.3

Bio1.LS1.3 – Use a model to describe how differentiation in a multicellular organism creates specialized cells that perform diverse functions to work together to meet the needs of the entire organism, including human development.

Big Idea(s):

Factors in a cell's immediate environment can activate and deactivate certain sets of genes. Different cell types arise from differences in the proteins they produce. This mechanism explains how a single cell can divide to become the a wide variety of different cells, tissues, and structures in multicellular organisms (plants, animals, etc.).

Scientific Ideas:

- Every organism is made of an enormous collection of cells and within this collection of cells there are many different types of cells.
- Organisms are organized into different parts made of different types of tissues of cells.
- Different cells perform unique functions, and these functions depend on the specialized structures within the cells.
- Most cells in a multicellular organism have a long period of interphase. During this time a cell is carrying out a narrow range of functions that contribute to the survival of the organism as a whole.
- The specialized structures within a cell are produced using information encoded in its genes.

- Each gene produces a specific protein or small set of proteins when it is expressed. These proteins carry out life's functions.
- All cells in a multicellular organism contain a complete set of the genes for that organism.
- Genes are turned on and off by a specific chemical reaction. For each gene, there is only one or a small number of chemicals that regulate its expression.
- Different cell types arise by expressing different genes from the complete set of genes they possess.
- The expression of genes in a cell determines the parts that develop in the cell, and therefore determine the role a cell plays as part of a larger organism.

Common Student Ideas:

- All of the cells in an organism are identical.
- Each cell is a closed system that is insulated from other cells and its surroundings.
- Cells have only the genes they need to perform their particular role and therefore a cell's' role is predetermined.

LS1.C: Organization for Matter and Energy Flow in Organisms

Guiding Question:

How do organisms obtain and use the matter and energy they need to live and grow?

The Biggest Ideas

Purpose

The purpose of this component idea is to help students understand the things that living things must take in energy and matter and have structures and processes that help them take in and process matter and/or energy.

Central Idea(s)

All living things require matter to grow and energy to facilitate motion, replace energy lost to their surroundings, and enable reactions that produce materials they can use to grow. Plants capture energy from the Sun and store it in matter as chemical energy. Animals get energy and matter from the food they eat. This food comes either from plants or animals that eat plants.

General Progression

Grade Band	Scale
K-2	Animals and plants need things we can see - Animals need food to live and grow. Plants need water and light.
3-5	Plants and animals need water and air. Animals use food for growth, warmth, motion. Plants can store matter to survive when there is no light.
6-8	Light provides energy to build sugars that store and transfer energy in living systems.
9-12	Energy moves through living systems as matter. Building up and breaking down compounds stores and releases energy.

This progression begins by introducing students to the materials that plants and animals must take in to survive and grow. Even in the earliest grades, students begin to discuss the differences between plants and animals with respect to their needs. By late elementary grades, they have two separate discussions about food. Students uncover that food gets broken down to give organisms the materials they need to survive. They also learn that food contains stored energy that replaces energy they use or lose during normal life activities. In middle school, students learn that matter and energy are fundamentally linked in living systems – transfers of usable energy are only possible when matter transfers between organisms.

K-2 Standards

By the end of grade 2: All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow. – NRC, 2012

Progression Across Grade Bands

Living things can only grow when they can get the materials they need. There are two questions nested in this statement: First, what does it mean to grow? And second, where do living things get the materials that they need to grow?

Scientists observe and measure things as they grow. Students can observe that a plant gets heavier as it grows, that the plant gets larger over time, or that they have gotten heavier since their birth.

Living things get the materials they need to grow from their surroundings. Plants and animals have different needs from their environment.

Plants can get larger and heavier when they have sunlight and water. Germinating seeds or growing plants without these resources allows students to see that the plants will not grow. In later grades, students learn that plants use carbon dioxide from the air to grow. It is not necessary to address the air or carbon dioxide since students are not typically aware that the air is made of invisible particles.

Animals get larger and heavier because they eat food. They can eat plants or other animals. This overlaps with LS1.A, where students consider the body parts that organisms use to meet their needs. For example, humans use their arms to reach for food. Since the structure of the arm includes elbows we can also bring food to our mouths to eat.

Students may have already learned that living things have other needs, such as air and water. These needs are deliberately left out of this progression because these materials are not used for growth or because they are invisible forms of matter.

In later grades, students will learn that matter is made of particles and that our bodies have internal structures that perform specific tasks. These two pieces of knowledge prepare students to discuss processes such as digestion where the food we eat is broken down inside of our bodies.

Current (2018 Implementation): K.LS1.1

K.LS1.1 – Use information from observations to identify differences between plants and animals (locomotion, obtainment of food, and take in/air gasses).

(Note: Plants and animals have some common needs. But it may not be possible to meaningfully talk about some of these needs with kindergarten students. For example, students understand “breathing” as something they do because they can feel things happening in their nose/mouth when they take a breath. Students might infer that other animals with a nose also breathe. However, students don’t know that air contains matter or that there are invisible and unique forms of matter, so students won’t appreciate what it means to “breath in oxygen.” Similarly, students may struggle with the idea that gas exchange also happens in plants. Plants don’t have a nose or visible parts where for gas to enter or leave their bodies. Instructionally, this standard should be more about exploration of the parts of plants/animals and less about matching different parts in plants and animals that perform the same function. It is acceptable for students not to know that plants take in air through their leaves.)

Scientific Ideas:

- Living things survive and grow when they get things they need from the environment.
- Plants cannot move from place to place, but animals can move in different ways.
- Animals use different body parts to get food.
- Plants and animals both respond to their environment.

Example(s) of Common Student Ideas:

- Only little plants like seedlings grow up.
- Big plants, like trees, do not grow.
- People are not animals.
- Plants do not sense their environment.

Revised (2025 Implementation): K.LS1.1

K.LS1.1 – Use information from observations to identify the differences between plants and animals and how they live and grow.

3-5 Standards

By the end of grade 5. Animals and plants alike generally need to take in air and water, animals must take in food and plants need light and minerals; anaerobic life, such as bacteria in the gut, functions without air. Food provides animals with the materials they need for body repair and growth and is digested to release the energy they need to maintain body warmth and for motion. Plants acquire their material for growth chiefly from air and water and process matter they have formed to maintain their internal conditions (e.g., at night). – NRC, 2012

Progression Across Grade Bands

Living things can only grow when they can get the materials they need. There are two questions nested in this statement: First, what does it mean to grow? And second, where do living things get the matter and energy that they need to grow?

Organisms grow when they take in matter. Food is a source of matter for animals. Plants take in matter from their surroundings. Matter refers to all the “stuff” in the universe – all living and non-living things. Matter is made of nothing more than tiny, invisible particles. Living things only get bigger and heavier if they can consume these particles.

Plants and animals have different ways of taking in matter. Animals get particles of matter by breaking down the food they eat. Plants do not eat;, they get matter from the air. The food that animals eat supplies them Animals grow by repurposing particles of matter from the food they eat.

All living things have ways to take in and release air – plants have small pores on the bottom of their leaves where particles can enter the plant. These pores can be seen with a hand lens. It is possible to see bubbles of gas leaving the leaves of aquatic plants when light is present. Animals have external (mouth, nose, gills, etc.) and internal structures for gas exchange. Although students have firsthand experience with breathing, they may not associate the process of breathing with taking in matter. It is not necessary to address about specific gases (e.g., carbon dioxide and oxygen) until middle school.

Food is also a source of energy. Animals constantly expend energy – they move around (motion energy) and are their bodies lose warmth as they transfer energy to the surroundings. Animals eat food to replace this spent energy. Food must be a form of stored energy. Our bodies must have a way to store energy from food because we constantly move and constantly heat our surroundings.

Plants require energy, but this may not be apparent because plants don’ not move around and don’ not feel warm to the touch. There are at least two possible ways to demonstrate that plants store energy. First, is to consider that plants must be able to store energy because they survive conditions when energy is not present – such as nighttime, or dormancy when they survive months without the leaves, they use to capture the Sun’s energy. Food chains support the inference that plants must store energy. The purpose of a food chain ist to trace the diets of consumers backward to lower sources. In all ecosystems, the food chains will lead back to organisms that create energy from non-living sources. It is important for students to understand that plants produce energy so that they can grow. Humans and animals take this energy for their own purposes.

There are things that people might eat that are not “food” because our bodies cannot use them to make energy or for growing. For example, water is necessary for all living things, but animals do not use water for growing and so water is not food. (Students should have learned that plants do use water to grow in the primary grades.) Students might observe nutrition information to observe that some things that they might consume (such as diet sodas) are not food, in contrast with fruit juices are food. Nutrition labels use the Calorie to indicate that our bodies can digest the materials and use them for growth.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

6-8 Standards

By the end of grade 8. Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. Animals obtain food from eating plants or eating other animals. Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. In most animals and plants, oxygen reacts with carbon-containing molecules (sugars) to provide energy and produce carbon dioxide; anaerobic bacteria achieve their energy needs in other chemical processes that do not require oxygen. – NRC, 2012

Progression Across Grade Bands

Living things can only grow when they can get the materials they need. There are two questions nested in this statement: First, what does it mean to grow? And second, where do living things get the matter and energy that they need to grow?

Cells are the fundamental building blocks of all living things. All living things grow by producing new cells from existing cells. Even though they are tiny, cells still have mass and take up space – this is especially evidence evident as cells divide and produce large multicellular organisms. Organisms take in matter from their surroundings. Chemical reactions that occur inside of living organisms convert the different forms of matter to the materials needed for growth. Chemical reactions require energy to build larger molecules from smaller molecules.

The cores of stars are places where atoms of light gases can collide. At times these collisions take place at such great speeds that the two atoms fuse. When this happens, some matter from the original atoms is converted to energy. Light waves radiate this energy outward into space. Plants and other photosynthetic organisms can use the energy to drive the chemical reactions that build larger molecules from smaller molecules.

Plants take in water through their roots and carbon dioxide through their leaves. The chemical reactions that occur within plants capture the carbon from carbon dioxide and use it to produce stored energy. Sugar serves two purposes – plants can rearrange the atoms to materials they use for growth and plants can release the stored chemical energy to drive reactions that sustain them.

Many different types of organisms cannot produce their own sugars from carbon dioxide and cannot capture the energy transmitted by light. This means that these organisms depend on other organisms to provide usable sources of matter and to provide stored energy. Food provides consumers with matter for growth as well as stored, chemical energy. This energy replaces the energy organisms lose as they move around, warm their surroundings, and carry out reactions that convert matter into forms that are useful for growing. There are a few different reactions that are used depending on the materials that are available.

It is only necessary to discuss the reactions of photosynthesis to communicate that atoms are rearranged and that the process of rearranging the atoms leads to materials with more energy stored than the original materials and with materials that are useful for growth.

Current (2018 Implementation): 7.LS1.9

7.LS1.9 – Construct a scientific explanation based on compiled evidence for the processes of photosynthesis, cellular respiration, and anaerobic respiration in the cycling of matter and flow of energy into and out of organisms.

Big Idea:

In the processes of photosynthesis and respiration, plants capture matter and energy in usable or storable forms. Other organisms use a separate set of reactions to release energy stored in the food they eat.

Scientific Ideas:

- Living organisms require both energy and matter.
- Organisms must replace the energy they lose to their surroundings whenever their bodies are warmer than the surroundings.
- Energy and matter are two separate concepts: Organisms require energy to carry out life functions and they need matter to grow and repair tissues.
- Materials that organisms need to build more cells exist in forms that must be converted before they can be used. For example, carbon in carbon dioxide cannot be used until plants incorporate it into sugars.
- Plants convert energy from the sun into stored chemical energy by rearranging atoms of chemicals they take in from the environment.
- In this process, plants make their own food, but other organisms must get food by consuming plants that have stored the sun's energy and captured matter.
- Food contains both matter (molecules for growth) and energy (stored chemical energy).
- Animals get food by eating plants or other animals.
- Food molecules can be broken down to release energy or rearranged to produce new molecules needed for growth.
- Organisms that perform aerobic respiration take in oxygen and this oxygen is a chemical that is incorporated into the chemical reactions that release the energy stored in food.
- Both plants and animals can use oxygen in a chemical reaction with sugars to produce energy and carbon dioxide.

- Some single celled organisms are also able to break down sugar molecules for matter and energy even without oxygen and therefore can survive and reproduce in areas without oxygen.
- The green parts of plants can change the composition of air. Air is required for things to burn, but there are different types of air and things will only burn in certain types of air. In a closed system, a burning candle will use up air that will allow things to burn and produce air that will prevent things from burning. A candle will burn longer in a closed system if there is a plant in the closed system with the candle. The plant is replenishing the air.

Common Student Ideas:

- The matter in the food we eat goes away if we use it for energy.
- Cell respiration turns the food that we eat into energy.

Revised (2025 Implementation): 7.LS1.7

7.LS1.7 – Develop a model using evidence that explains the process of photosynthesis, cellular respiration, and anaerobic respiration in the cycling of matter and flow of energy into and out of organisms.

9-12 Standards

The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example, aerobic (in the presence of oxygen) cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken, and new compounds are formed that can transport energy to muscles. Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems.

– NRC, 2012

Progression Across Grade Bands

Living things can only grow when they can get the very specific materials needed for growth. There are two questions nested in this statement: First: First, what does it mean to grow? And second, where do living things get the matter and energy that they need to grow?

Living things grow as cells divide. Cells can only divide when the materials needed to make new cell parts are available. These parts are made of combinations of four types of biomolecules: carbohydrates, lipids, proteins, and nucleic acids.

Producers get the matter and energy for growth from their surroundings. Chains or rings of carbon are a central component of all biomolecules, which means that all living things require sources of carbon for growth. Only certain forms of carbon are useful for growth. Plants get carbon to build sugars from carbon dioxide from the air or dissolved in water. Building sugars from molecules of carbon dioxide requires energy and plants obtain this energy from the Sun's light. Plants have a variety of pathways – sequences of chemical reactions – that produce the biomolecules needed for growth from the sugars produced in photosynthesis. Plants have various pathways – sequences of chemical reactions – that produce the biomolecules needed for growth from the sugars produced in photosynthesis. These chemical pathways depend on energy provided by both light and chemical energy stored during photosynthesis.

Food chains of ecosystems reveal all usable carbon originates from plants. Consumers get matter and energy from food in the form of larger biomolecules that are broken down into smaller subunits. For example, proteins provide amino acids while nucleic acids provide nucleotides. These smaller bits get absorbed and contribute to the pool of materials available for constructing new cells and tissues. The largest portion of the pool of materials comes from a variety of pathways that produce the different biomolecules. These pathways provide ways to transform one type of biomolecule into other another type. For example, pathways such as glycolysis, pentose phosphate pathway, or Kreb's cycle produce intermediate forms of carbon that can be used to make nucleic acids, amino acids, or lipids from carbohydrates. Other pathways can regenerate carbohydrates from these other biomolecules.

Students should already understand that animals and other organisms lose energy to their surroundings, and that they expend energy during their daily activities. All organisms need energy to carry out the chemical reactions that rearrange various forms of carbon-based biomolecules. Growth depends on these chemical reactions, therefore growing requires energy. Plants capture the Sun's energy and use it to carry out chemical reactions that store energy in sugars. All living organisms possess pathways that release stored chemical energy.

Revised (2025 Implementation): Bio1.LS1.4, Bio1.LS1.5, Bio1.LS1.6

Bio1.LS1.4 – Create, or use, a model to describe how the process of photosynthesis converts light energy into the stored chemical energy of bonds created by converting CO_2 and H_2O into sugar and other organic molecules.

Big Idea(s):

Plants get energy from the Sun and matter from their surroundings. Plants transform energy from the Sun into chemical energy stored in sugars. These sugars also provide matter for plants to grow as well as energy.

Scientific Ideas:

- Plants can produce energy from sunlight;, however, there are periods of time, such as at night and during periods of dormancy, where plants must survive without producing energy. This is possible because plants produce energy-storing compounds.
- All matter is made of atoms. Individual atoms are so small that they are not visible. Groups of these atoms can exist as solids, liquids, and gases. These atoms get rearranged during chemical reactions.
- Atoms have unique identities, such as carbon, hydrogen, and oxygen, and these identities do not change during chemical reactions.
- Reactions in plants build larger, less stable compounds from more stable starting points. Adding energy decreases the stability of a system – Work (energy transfer) is done to lift each successive block higher and higher onto a growing tower. Each block represents another addition of energy into the system. As the tower gets taller, it becomes less stable. A nudge to the top of the tower can be enough to unleash the

stored energy and lead the blocks to a more stable configuration. Chemical energy works in a similar manner. Organisms build “towers” by creating larger and less stable molecules from smaller molecules, such as glucose from molecules of carbon dioxide and water.

- Light provides the energy for photosynthesis. This energy is used during the reactions of photosynthesis to build fewer stable compounds (sugars) from a starting point of more stable compounds (carbon dioxide and water). This energy transfer is analogous to the energy transfer that takes place as each block is placed onto a growing tower.
- A limited number of organisms can capture the energy carried by light and use it to build more complex, less stable molecules. These organisms include plants and a variety of aquatic microorganisms.
- Organisms that can capture energy transferred by light produce pigments that make the energy conversion possible.
- Plants can assemble the simple sugars produced by photosynthesis into starches, which are collections of glucose. Starches provide plants with stores of energy they can access during times of environmental stress. Starches also function as stored carbon stores that plants can use to continue to grow. Binding glucose in insoluble starches prevents the leeching of glucose from plants.

Organization of plants into structures that support chemical reactions:

- Water uptake occurs in plant roots and gas exchange occurs primarily in leaves and where other pores allow gas to enter.
- Living things are made of cells that are further organized into tissues. Plants contain organized tissues with structures to enable water transfer water and gas exchange.
- Water can move across cell membranes and between cells in specialized tissues.
- Water loss at the surface of plant leaves creates pressure that draws water from the soil and through specialized tissues that deliver water to the different parts of a plant.
- Chemical reactions inside living things reorganize the atoms from the materials they take in into a different compounds that are incorporated into their own materials.

<u>Common Student Ideas:</u>

- Plants grow and produce fruits, leaves, tubers, etc. so that animals will have food to eat.
- Plants absorb water and convert the water into plant materials.
- Plants grow and get heavier because they get the materials they need from the soil.
- Plants absorb soil through their roots and convert the soil into plant materials.
- Bubbles that form under water do not contain matter.
- Energy is a physical substance that flows into plants.

Bio1.LS1.5 – Construct an explanation based on evidence that matter taken into an organism can be broken down and recombined to make macromolecules necessary for life functions.

<u>Big Idea(s):</u>

At all scales, growth in living systems depends on the production of carbon-based sugars, nucleobases, and amino acids. Living things use stored chemical energy to assemble these smaller parts and a small number of different elements into the four types of biomolecules that make up the cells and tissues of living things.

Scientific Ideas:

- Living things grow when they take in materials (atoms) from their surroundings, rearranging the atoms from these materials into new compounds, and using these new compounds to build more cells and tissues.
- During chemical reactions, the identities of the elements involved in the chemical reaction do not change.
- Cells and tissues are made of four primary types of molecules: carbohydrates, nucleic acids, sugars, and lipids. Carbon is the central element in each of these compounds (Nucleic acids, $C_nH_{2n}O_nP_n$; Carbohydrates, $C_nH_{2n}O_n$; Proteins, CHNO; Lipids, $CH_2(CHO)CH_2OH$).
- Photosynthesis combines carbon, hydrogen, and oxygen to produce very simple sugars. Plants can produce sugars from atmospheric carbon dioxide. Animals can produce sugars from existing sugars or other carbon-based biomolecules, but not from carbon dioxide.
- The simple sugars produced during photosynthesis can be used to make other sugars or lipids because these molecules are only made of carbon, hydrogen, and oxygen.
- Photosynthesis provides the carbon-based sugars used to produce nucleic acids. However, organisms must also get phosphorous and nitrogen to produce a phosphorous-containing phosphate group, and nitrogen-containing nucleobases to produce a complete nucleotide.
- Photosynthesis provides carbon-based sugars used to produce amino acids. However, the R-groups that differentiate amino acids require elements other than carbon, hydrogen, and oxygen – such as nitrogen and sulfur. Organisms acquire these materials from their diet/surroundings.
- Living things contain pathways that produce many of the materials they require for growth, but there are also materials that cannot be produced de novo. For example, humans can make 13 different amino acids, but nine amino acids must come from the food we eat.
- Organisms pool and recycle many materials used for growth and use these pools to supplement the cellular production of the materials.
- Larger molecules of each of these smaller types are built from the simplest units of each type of molecule; For example, glycogen and starch store glucose in animals and plants respectively.
- Growth requires energy because the reactions that build larger materials from smaller materials also require energy. Since each biomolecule is the product of a biochemical pathway, it possesses stored chemical energy that can potentially support growth.

- As organisms build increasingly complex molecules, the amount of energy stored in each molecule increases. For example, a monomer of glucose contains less energy than a cellulose/glycogen polymer made from glucose.
- Organisms store chemical energy in increasingly complex molecules and harvest the energy at times when they cannot directly take in energy. For example, plants break down these energy- storing molecules at night or during dormancy and animals can survive when they are not eating – such as during hibernation or periods between meals.

Common Student Ideas:

- Animals grow by incorporating plant cells into their own tissues.
- Carbohydrates are only used for energy.

Bio1.LS1.6 – Create, or use, a model to describe how cellular respiration transforms stored chemical energy of food resulting in a net transfer of energy. Compare aerobic respiration to alternative processes of glucose metabolism.

Big Idea(s):

Living systems possess enzymes that can capture There are chemical reactions in living organisms that gradually convert the energy stored in a molecule of glucose in smaller, more accessible chemical compounds.

Scientific Ideas:

Matter as a mechanism for energy storage and transfer in living systems:

- *Chemical compounds as a mechanism for energy storage:* - Chemical reactions will occur whenever conditions make it possible for a group of atoms to move from an arrangement that is larger and less -stable to arrangements that are smaller and more stable. Consider a tower of blocks. A builder does work as they lift each successive block onto the growing tower – work is the active transfer of energy to the block system. A nudge to the top of the tower can be enough to topple the tower, which will unleash the stored energy and lead the blocks to a more stable, collapsed configuration. In their most stable/lowest energy arrangement, each block sits on its own. It is also possible to arrange the blocks into smaller, more stable towers blocks that stand on their own. These smaller block towers are still unstable relative to the individual blocks, but their instability also means that they continue to possess an amount of stored energy. Chemical energy works in a similar manner. Molecules like glucose are examples of tall towers. Under the right conditions, organisms reallocate some of the stored energy into smaller, more stable molecules.
- *Concentration gradients as a mechanism for energy storage:* - All matter is made of particles and the arrangement of these particles in a space provides a way to for a system to store energy. It is a natural law that particles will end up in arrangements

where they are evenly distributed in a space as long as they can move freely and without the influence of outside forces. A uniform arrangement of particles – even distributions in space – is the most stable and therefore the lowest energy way to arrange the particles. This is like the blocks of a toppled tower in the earlier analogy. It is possible to store energy in the blocks by assembling them into a tower and it is possible to store energy in the system of particles by creating arrangements where some areas have many particles clustered together (high concentrations), and other connected areas have fewer particles (low concentrations). The natural tendency of these particles will be to return to their lowest energy arrangement – even distribution. The system of particles releases its stored energy as the concentration gradient goes away and particles become evenly distributed.

- *Extra electrons as a mechanism for energy storage:* – Negatively charged electrons are one component of every atom. Every molecule – group of atoms – possesses a typical number of electrons. Adding an extra electron to a molecule requires energy since the other electrons in the molecules will push against the extra electron – like charges repel. This is the same idea as lifting each additional block onto a growing tower of blocks – work is done to add the additional electron. Just like the growing tower, the stored energy in the form of the extra electron makes molecule less stable/more reactive. Molecules have different chemical compositions and different shapes that affect whether they might be able to accept extra electrons. If possible,
- *Transfer of matter as a mechanism for energy transfer:* - Living organisms are made of many different molecules. The amount of stored chemical energy depends, in part, on the particular elements in each compound. This is similar to the way that block towers built to different heights store different amounts of energy. Adenosine di-phosphate particles (ADP) store energy when they combine with a phosphate particle. Later, the added phosphate can transfer to a different particle. Removing the phosphate effectively "shortens the tower" resulting in a lower energy and more stable ADP. The stored chemical energy of some other particle increases as it receives the phosphate group, and the particle becomes less stable.
- *Transfer of an electron as a mechanism for energy transfer:*. The electrons in every different molecule push against the addition of extra electrons to varying degrees. Some molecules offer little resistance to the addition of electrons, while other already unstable molecules may not accept an additional electron. Energy transfers occur when extra electrons move towards molecules that offer less resistance to the extra electron.

Enzymes facilitate energy transfer in living systems.

- *It is possible for energy to transform from one type of energy to another:* - Living organisms have mechanisms that transform stored energy between stored chemical energy, energy in, a concentration gradient, and energy as extra electrons.
- *Proteins facilitate energy transfers in living systems.* There are enzymes that participate in the addition of a phosphate group that adds stored chemical energy. There are enzymes

that add a phosphate group that adds stored chemical energy. Other proteins can remove this phosphate group, which returns to the lower energy state. During the removal of , this phosphate group the protein can causes the pumping of particles across a membrane to create a concentration gradient. Proteins can channel the tendency of these particles to redistribute to a uniform arrangement and capture the energy released as this happens. Other proteins facilitate the transfer of high- energy electrons to new molecules and capture the energy released as this happens.

Feedback mechanisms influence the capture of energy from glucose:

- Glucose is a large and less stable compound. Stored chemical energy provides the "nudge" needed to begin the release of chemical energy that was stored when the glucose molecules were initially assembled. After the release of an initial bit of energy
- Less energy is required to force electrons onto oxygen, which makes it a good place for electrons to end up. When oxygen is present, proteins are able to facilitate the transfer of electrons from other electron carriers onto the oxygen. When oxygen is present, proteins facilitate the transfer of electrons from other electron carriers onto the oxygen. These proteins store the released energy by building larger compounds. Without oxygen, the electrons accumulate in already high- energy compounds. Anaerobic pathways can regenerate lower- energy electron transporters so that glucose will continue to yield minimal amounts of energy.

Common Student Ideas:

- A chemical reaction will occur whenever two different compounds are mixed.
- The enzymes found in humans or other living organisms are all unique and are found in no other organisms.
- Energy is a physical substance in living things.

LS1.D: Information Processing

Guiding Question:

How do organisms detect, process, and use information about the environment?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to help students understand that living things have systems that gather information about their surroundings and then respond to this information.

CENTRAL IDEA(S)

All living things have sense receptors that detect information about their surroundings. Organisms that have a central nervous system process the things they detect from the surroundings in their brains which guides their responses. As organisms process information, their brains store memories that influence the way they respond.

GENERAL PROGRESSION

Grade Band	Scale	Sensing and Responding
K-2	External Structures	Animals have external/visible sensory parts (e.g., ears, eyes, nose) that gather information which that guides their responses.
3-5	Internal structures	Specialized receptors (e.g., ear drum, retina, nasal cavity) in sensory parts collect information, and the brain processes and stores the information.
6-8	Cells/Tissues	Tissues in specialized receptors detect specific inputs and create signals that travel along nerve cells to the brain. Connections among cells in the brain drive actions and/or store memories.
9-12	Cells/Tissues	The internal structure of the brain is organized into regions and circuits.

Information processing contains two strands – gathering information from the environment, and then internally processing and responding to this information. The earliest discussions about how the information is processed focus entirely on the ways that organisms respond to the information they collect. For example, a butterfly may see a brightly colored flower and respond by flying to the flower. Later in elementary school, students learn that organisms have internal structures, which may include a brain, and at this point, they can address that the eyes gather information which is sent to the brain and the brain then guides the organism's response. When students learn about cells, they are able to understand how signals are transmitted between their sensory receptors and the brain and how brains store memories that affect the way they respond to stimuli.

K-2 Standards

By the end of grade 2. Animals have body parts that capture and convey different kinds of information needed for growth and survival-for example, eyes for light, ears for sound, and skin for temperature and touch. Animals respond to these inputs with behaviors that help them survive (e.g., find food, run from predator). Plants also respond to some external inputs (e.g., turn leaves toward the sun).
– NRC, 2012

Progression Across Grade Bands

Animals need to be able to make observations about their surroundings to survive. Students are learning that different parts of their bodies to make this observation. Standards in the LS1.A component idea should lead students to understand that the structures of these parts are specialized for their function. For example, the shape of the outer ear helps organisms gather sound.

Students can develop models that communicate how body parts work together to perform specific tasks. For example, for hummingbirds to get food they use their wings to hover and their eyes to see. When they see a flower with their eyes, they use their wings to fly to the flower and their beaks help them to get nectar from inside the flower. Using words or pictures to write algorithms that communicate how the body parts work together is an excellent opportunity to introduce computational thinking in the earliest grades.

This component idea will develop further as students learn about the internal structures that act as sensory receptors within larger body parts and send information to the brain that guides their actions. After learning about cells in middle school the students can address the types of cells that interact to detect information from the surroundings and how different types of cells send signals to the brain for processing.

Current (2018 Implementation): K.LS1.3, 1.LS1.3

K.LS1.3 – Explain how humans use their five senses in making scientific findings.

Big Idea:

Organisms have body parts that take in information from the environment, and they respond to those inputs.

Scientific Ideas:

- An input is any bit of information that an organism can collect about its environment.
- Each different sense collects a different type of information about the environment.
- Organisms can experience the same event with more than one sense at a time.

- Organisms have different body parts that are involved with each different sense:
    - Eyes are used for sight.
    - Ears are used for hearing.
    - Skin is used to feel temperature and touch.
    - Mouth is used to taste.
    - Nose is used to smell.
- Organisms choose how they will act using information they collect about the environment (e.g., look for shade when it's sunny outside).
- Organisms make decisions that will help them survive.
- There are some events that occur that humans are not able to detect using their senses because the events happen too slowly or quickly, are too big or small, or are too far away.

Common Student Ideas:

- All organisms see the same way humans do.
- ...

1.LS1.3 – Analyze and interpret data from observations to describe how changes in the environment cause plants to respond in different ways.

Big Idea:

Plants may not have the same body parts as animals, but they still respond to their environment.

Scientific Ideas:

- Plants have different external features than animals.
- Plants have needs that must be met for them to survive – light and water.
- There are many different types of plants, but they have some common features.
- Responding to their environment will help a plant survive.
    - A potato vine that grows towards light in an otherwise dark place will help meet its need for light.
    - Seedlings planted close together will grow taller as they all try to get as much light as possible.
    - Plants will orient different parts (leaves and flowers) towards the sun.
    - Peas, beans, types of squash, etc. have tendrils that they can wrap around things to help them grow upwards even without a rigid stem/trunk.

Common Student Ideas:

- Plants have senses.
- Plants only move when something happens to them (e.g., the wind blows).
- ...

Revised (2025 Implementation): K.LS1.3, 1.LS1.3

K.LS1.3 – Explain how animals, including humans, use their five senses to interact with the environment.

1.LS1.3 – Analyze and interpret data from observations to describe how plants respond to changes in the environment (e.g., turn leaves toward the sun).

3-5 Standards

By the end of grade 5. Different sense receptors are specialized for specific types of information, which may then be processed and integrated by an animal's brain, with some information stored as memories. Animals are able to use their perceptions and memories to guide their actions. Some responses to information are instinctive-that is, the animal's brains are organized so that they do not have to think about how to respond to certain stimuli. – NRC, 2012

Progression Across Grade Bands

The two strands of this progression (how organisms gather information and how organisms process and respond to information) draw closer together now that students have learned that organisms contain organs (e.g., a brain) that processes information from their surroundings.

In earlier grades, students learned that organisms have structures (e.g., ears, eyes, nose, etc.) that they use to gather information about the world and then the organisms respond to this information using other parts of their bodies (e.g., legs, wings, teeth, etc.) in ways that help them survive and reproduce.

These discussions continue as students learn that each sensory structure contains receptors that sense specific inputs. Students learn that these receptors, such as the ear drum, receive a stimulus and send information to the brain which processes the input. Since students have not yet learned about cells, it is not necessary to talk about cells within these receptors or how signals travel from the receptors to the brain. It is sufficient for students to understand that inputs are processed by the brain and that the brain causes the organism to respond.

Students also learn that the brain can store memories and use these memories to guide the organism's response. Some actions controlled by the brain take place without thinking – breathing happens automatically. Other portions of the brain remain available for sensing and responding to the environment.

Current (2018 Implementation): 5.LS1.1

5.LS1.1 – Compare and contrast animal responses that are instinctual versus those that are gathered through the senses, processed, and stored as memories to guide their actions.

<u>Big Idea:</u>

Some organisms have a brain, which is an organ that guides the actions of the organism. Their brains can perform some tasks without dedicated thought, while other portions of the brain process input that determine the behavior of the organism.

Scientific Ideas:

- The brain is an organ in some animals that guides the actions of the organism.
- There are some behaviors that happen without intentional thought (e.g., breathing happens in all humans).
- Organisms gather information about their surroundings using their senses and collect bits of information during their experiences.
- Organisms have both internal and external features and some of these features capture information.
- Larger body parts have smaller structures, including internal structures that may not be visible. These structures contain sets of receptors that collect and gather information.
  - The retina of the eye detects light.
  - The ear contains an eardrum that detects vibrations in the air.
  - The skin has receptors that can detect a difference in the temperature of two things.
  - The tongue has taste buds that detect different tastes.
  - The olfactory nerves/tract are a region within the nose where chemicals in the air can bind and be detected.
- Sense receptors send information to the brain.
- The brain processes inputs from the senses and this information guides immediate actions and is also stored as memories.
- Responses to an environment are based on processing inputs and memories at the same time.

Common Student Ideas:

- Humans are the only animals with brains.
- …

Revised (2025 Implementation): 5.LS1.1

5.LS1.1 – Compare and contrast animal responses that are instinctual versus those that are learned by gathering information through the senses, which is then processed in the brain and stored as memories to guide their actions.

6-8 Standards

By the end of grade 8. Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical) transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories. Changes in the structure and functioning of many millions of interconnected nerve cells allow the combined inputs to be stored as memories for long periods of time. – NRC, 2012

Progression Across Grade Bands

The introduction of cells and the hierarchical organization of multicellular organisms in middle school provides a foundation for general discussions about nerve cells. Students learn that each different type of nerve cell responds to specific types of input, which can either be electromagnetic (light), mechanical (e.g., hearing, touch), or chemical (e.g., smell, taste). Strands of nerve cells carry the signals from the receptor cells to the brain. The brain can send out signals through the same network of nerve cells that direct the activity of other groups of tissues. Understanding that messages travel through the nervous system is more complex than earlier grades where receptors perceived inputs and then the brain processed the inputs without regard for how the brain was connected to the sensors.

In earlier grades, students learned that the brain is organized in a way that allows it to guide some tasks without thinking about those tasks and that inputs are stored as memories. Now that students are aware that the brain is composed of many neurons, they are prepared for basic discussions of how the brain stores memories as the strength of the connections between groups of neurons changes over time and with repeated use or lack of use.

Animals with a central nervous system gather inputs from their surroundings using different sense receptors. The sense receptors create a signal in response to a specific input. This signal travels along a network of nerve cells to the brain. For example, exposure to light causes rod and cone cells in the eye to create signals that are carried to the brain by nerve cells in the optic nerve.

The brain's primary task is to processes the signals from all sense receptors in the body. If a person looks at a drawing of a circle on paper, the brain receives input from every rod and cone cell in the eyes at once. The brain processes these simultaneous signals and then creates an image of the person's surroundings from the information it receives. Processing occurs by activating connections between certain nerve cells in response to inputs. There are patterns in the connections between nerve cells where similar circuits of nerve cells process similar types of input. If the person has past experiences to know about shapes, and specifically shapes called circles, then some predictable circuits will activate.

Learning involves the strengthening of connections between circuits. For example, learning to navigate in a first-person video game involves circuits that are activated by recognizing objects such as walls and the coordination of these circuits with the circuits that process tactile inputs as users become familiar with using their fingers to operate the game controls. Over time, the connections between the involved circuits get stronger and the player learns to move their character without consciously thinking about how their fingers move to operate the controls.

In high school, students will build on the ideas of learning and memory storage by discussing memory recall and the way that emotions associate with memories.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): 7.LS1.5

7.LS1.5 – Obtain and communicate information to provide evidence that illustrates the causal relationships between information received by sensory receptors and behavior, both immediate and over longer time scales.

9-12 Standards

In complex animals, the brain is divided into several distinct regions and circuits, each of which primarily serves dedicated functions, such as visual perception, auditory perception, interpretation of perceptual information, guidance of motor movement, and decision- making about actions to take in the event of certain inputs. In addition, some circuits give rise to emotions and memories that motivate organisms to seek rewards, avoid punishments, develop fears, or form attachments to members of their own species and, in some cases, to individuals of other species (e.g., mixed herds of mammals, mixed flocks of birds). The integrated functioning of all parts of the brain is important for the successful interpretation of inputs and generation of behaviors in response to them. – NRC, 2012

Progression Across Grade Bands

Neurons are a specialized type of cell in the brain that send and receive signals. A neuron can connect to many other neurons. This allows a single neuron to receive signals from more than one other neuron. A single neuron can also send a signal to more than one other neuron. The network of connections in the brain can become extremely complex because each neuron can connect to so many other neurons. Specialized cells can be activated by specific inputs. These cells send signals to the brain and the brain processes these signals in circuits of neurons. The brain can also generate signals that travel to different types of specialized cells that allow an organism to respond to the stimulus.

There are patterns where the same type of input will activate similar circuits of neurons. The brain is organized and circuits that are responsible for related tasks are located close to each other. The brain is organized, and circuits responsible for related tasks are close to each other. Data collected showing which circuits are activated by certain events reveal that the brain is organized into regions and the circuits in each region are responsible for a limited range of specialized tasks.

Emotions are created by activity in circuits in the brain. Activity in some parts of the brain is expected for a certain stimulus. For example, circuits in the part of the brain that processes input from the eyes are likely to have activity when an object moves suddenly across a person's field of view. There will also be activity in the parts of the brain that generate emotions. These emotions help an organism survive. If the moving object causes the person to feel surprised, their body is more prepared to move quickly out of the way of something like a falling object. Emotions also drive organisms to sense and respond to social connections that lead to groups which are an advantage to members of the group.

Memories form when the brain uses the same circuits over and over. For example, similar neural circuits activate each time we see the same object or smell a familiar scent. With repeated use, the connections between the nerve cells become stronger. Some of the connections can become so strong that they can be activated without the typical external stimulus. For example, we can visualize our best friend's face or seem to smell a familiar soap even when that friend or soap are not around us. Circuits may also trigger other circuits – a particular perfume may activate one set of nerve cells that is so tightly associated with another set of circuits that we recall memories of a person who wore that perfume.

The brain receives countless stimuli all at once. The brain must coordinate all these inputs and respond accordingly. There are circuits in the brain that are responsible for tuning out distractions. A person's interpretation and response to stimuli depends on multiple circuits activating and regulating their response.

Revised (2025 Implementation): Bio1.LS1.7

Bio1.LS1.7 – Construct an explanation from evidence to explain how the integrated functions of the brain in complex animals results in successful interpretation of input and generation of behaviors in response to those inputs.

Big Idea(s):

A single stimulus will activate many circuits across different regions of the brain. Some of these circuits help regulate the organism's behaviors in response to the input. Other circuits

Scientific Ideas:

- Organisms have a variety of sense receptors that generate signals in response to specific types of external stimuli – chemical inputs, relative temperature changes, electromagnetic inputs (light), and mechanical inputs (touch, pressure).
- Nerve cells throughout an organism's body transmit signals from receptor cells to the brain.
- When a signal from the body's receptors reaches the brain, it travels through circuits of neurons in the brain.
- The structure of a neuron provides a way for it to make a physical connection to and from multiple other neurons.
- When a signal reaches the brain, the branching connections between neurons provide a way for a single stimulus to activate multiple parts of the brain at one time. For example, one part of the brain may construct an image of the person's surroundings the connected circuits allow another part of the brain to associate certain emotions with these responses.
- Repeated stimuli of a particular circuit strengthen connections between the neurons in that circuit.
- Over time, connections between circuits can become so strong that a particular stimulus may activate circuits that may or may not be useful in an organism's particular setting.

- The brain can generate signals that travel outward to specialized cells that generate a motor response.
- The circuits in the part of the brain associated with particular emotions influence the way an organism responds to its surroundings.

<u>Common Student Ideas:</u>

- Each sense occurs at a particular sensor. For example, sight happens at in our eyes.
- Each memory that we have is like a folder in a file cabinet.

LS2.A: Interdependent Relationships in Ecosystems

Guiding Question:

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

The Biggest Ideas

Purpose

This component idea helps students understand that there are different types of interactions between plants and animals in ecosystems. These interactions exist because organisms have intersecting needs and share a supply of limited resources.

Central Idea(s)

This progression is about the connections between the components of ecosystems - plants, animals, and the surroundings. Most ecosystems depend on plants to provide the inputs of matter and energy into the ecosystem. Plants also depend on animals and on decomposers. Healthy soil is crucial to a stable ecosystem and is nourished by decomposition. Population growth depends on many of the same things that determine the health of individuals in the population.

General Progression

Grade Band	Scale	Nature of Interaction
K-2	Plants & Animals	Resources for living things come from the environment (food, water, shelter, light)
3-5	Plants, Animals, & Microbes	Resources move among living things and back and forth between living things and the physical environment.
6-8	Populations	Resources are limited. Limited resources cause competition and various interactions among individuals among populations.
9-12	Ecosystems	Resource availability create limits on the number of organisms and populations in an ecosystem – a carrying capacity.

This progression begins with students understanding that there are connections between different types of living things and the non-living environment; animals eat plants, plants provide nesting places for animals, animals benefit from pollination, etc. After observing the types of connections around where they live, students can look at a variety of ecosystems to observe that there are similarities in the structures of ecosystems. For example, the food chains in many ecosystems originate with plants. Students begin to learn to describe general roles across ecosystems. By middle school, students examine populations to see that the growth and connections of populations face are limited by many of the same factors that organisms depend on.

K-2 Standards

By the end of grade 2. Animals depend on their surroundings to get what they need, including food, water, shelter, and a favorable temperature. Animals depend on plants or other animals for food. They use their senses to find food and water, and they use their body parts to gather, catch, eat, and chew the food. Plants depend on air, water, minerals (in the soil), and light to grow. Animals can move around, but plants cannot, they depend on animals for pollination or to move their seeds around. Different plants survive better in different settings because they have varied needs for water, minerals, and sunlight. – NRC, 2012

Progression Across Grade Bands

This progression is about the connections between the different components of ecosystems - plants, animals, and the surroundings. Students should see a variety of different ways that plants and animals are connected to each other. These connections can be direct or indirect.

If students know that skunks eat berries, then they are likely to see a direct connection between plants and animals. It may be harder for students to see the indirect connections. Plants and animals need some of the same things, such as water. If students know that plants and animals get water from their surroundings then they are likely to see the connections between either plants or animals and their surroundings, but there is also a less obvious, indirect connection between plants and animals because they both get water from their surroundings. *(Note: There is no expectation that students should be able to differentiate between direct and indirect connections.)*

After giving students time to explore their surroundings, they can create system models such as drawings, words, or pictures of the different types of living things near their homes and communities. Students can describe the meaning of different lines that show connections between living things. For example, a line between two plants might mean that one type of plant only grows in the shade of a big tree. A line between a caterpillar and a tree might show that the caterpillar lays their eggs in the tree. If students create system models, then they are more likely to uncover less obvious connections between living things connections.

Encourage students to compare the types of living things that live in different settings around campus. For example, different plants may be found in a sunny patch of grass compared to the plants that might live where runoff from an air conditioning unit gathers, or under the dry shade of a large tree. These initial observations about the types of plants growing in different settings can illustrate the way that the physical setting influences what types of organisms can live in a certain place.

In later grades, students will use more specific system models, such as food webs to show how matter flows through an ecosystem.

Current (2018 Implementation): 1.LS2.1, 1.LS2.2, 1.LS2.3, 2.LS2.1

1.LS2.1 – Conduct an experiment to show how plants depend on air, water, minerals from soil, and light to grow and thrive.

Big Idea:

Plants depend on their surroundings to get the things that they need.

Scientific Ideas:

- A plant is alive – it can grow and make more plants.
- Plants have different structures and some of these structures take in materials from the environment around them.
- Plants generally require soil to survive because soil provides them with water and some nutrients.
- The soil provides plants with water that they get using their roots.
- Plants get sunlight by being in the sun, but some plants also need shade because too much sun will harm them.
- Plants get some minerals from the soil through their roots and will not grow if they cannot get these materials.
- In nature, minerals come from the soil, but people have also found ways to grow plants without soil as long as the plants still get minerals delivered to their roots.
- Places will have different amounts of sunlight, temperature, water, wind, etc.
- Different types of plants have unique needs and will only grow where their needs are met.

Common Student Ideas:

- Since plants don't have the same body parts as animals, they don't take things from around them.

1.LS2.2 – Obtain and communicate information to classify plants by where they grow (water, land) and the plants' physical characteristics.

[Note: The intent of this standard is not to arrive at a formal classification (e.g., land plant vs aquatic plant or angiosperm vs gymnosperm), but rather to sort plants in ways that reveal patterns in the appearance of plants that correspond with where the plants live.]

Big Idea:

Different plants survive better in different settings because they have varied needs for water, minerals, and sunlight.

Scientific Ideas:

- Plants have the same basic parts, and these parts have the same function in most types of plants.
- Plants have the same needs for survival – air, water, minerals, and light.
- Plant survival means that the plant can complete its life cycle, not just grow/stay green.
- Plants live in most places on Earth where there is enough light and air for them to survive.
- No type of plant can survive in all conditions.
- Plants that live in different places look very different from each other.
- There are patterns in the appearance of plants depending on where they grow (e.g., plants that grow in the shade often have larger leaves than plants that grow in bright light).
- Plants have different tolerances for sunlight.
    - Some plants will suffer if they experience too much heat.
    - Some plants will not grow or make flowers if they do not experience enough sunshine.
- Plants have different requirements for water.
    - Some plants can survive in very wet places that would cause other plants to rot.
    - Some plants can survive in very dry places that would cause other plants to dry out.
- Plants have different mineral requirements.
    - Some plants can live in very poor soils (sand and clay), while others require very rich soils (soils that have accumulated lots of plant materials over time – compost, mulch, etc.).

Common Student Ideas:

- A plant will grow as long as it gets sunlight and water.
- Plants can be moved from where they live and be planted in a very different place but still survive.

1.LS2.3 – Recognize how plants depend on their surroundings and other living things to meet their needs in the places they live.

Big Idea:

Plants are especially dependent on other living things to meet their needs because they cannot move around.

Scientific Ideas:

- Plants have the same basic parts, and these parts have the same function in most types of plants.
- Plants have the same needs for survival – air, water, minerals, and light.

- Plants cannot move from place to place.
- Every type of plant has conditions where it will grow best.
- Plant seeds may be more likely to survive when they are moved away from the parent plant so that young plants do not take resources from the parent plant.
- Animals collect seeds and eat fruits and when these animals move, they carry the fruit and seeds along with them.
- Plant seeds are alive and new plants can grow from these seeds.
- Seeds are tough and can survive harsh conditions, including being eaten by an animal.
- Plants have pollen that must be moved from one plant to another in order to make new plants – animals move the pollen for the plants.

Common Student Ideas:

- A seed cannot survive being eaten by an animal.

Revised (2025 Implementation): 1.LS2.1, 1.LS2.2, 2.LS2.1

1.LS2.1 – Conduct an experiment to show how plants depend on air, water, minerals from soil, and light to grow and thrive.

1.LS2.2 – Obtain and communicate information to classify plants by where they grow (i.e., water, land) and the plant's physical characteristics.

2.LS2.1 – Use evidence and observations to explain that many animals use their body parts and senses in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air.

3-5 Standards

By the end of grade 5. The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Either way, they are "consumers." Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plants' parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil for plants to use. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.
– NRC, 2012

Progression Across Grade Bands

This progression is about the connections between the components of ecosystems - plants, animals, and the surroundings. There are two major developments in this grade band. The first is the concept of an ecosystem and the second is the idea of that there are patterns in the variety of interactions across ecosystems. Specifically, students should see that all ecosystems have organisms that eat plants and other organisms that return nutrients to the soils for plants.

As students think about the way that organisms interact (e.g., animals get their food from other animals, and ultimately from plants, decomposers replenish soils) it is possible to introduce the idea of an ecosystem as a connected group of organisms which that all survive under the conditions at a certain place. It is possible for students to see how changing conditions will impact ecosystems once students see the connections between the organism and the physical environment as factors that define an ecosystem.

In earlier grades, students may have created system models to represent the connections they learned about. Ideally, these system models showed connections between organisms in the students' own communities. Students can build on the experiences by modeling their community and progress to examining models of other groups of organisms. As students look across different systems and consider how organisms meet their needs, they are likely to uncover that all organisms eventually connect to plants. This idea of a food chain appears in this grade band. The instructional purpose of a food chain is to help students by trace the source of food back from any organism to the thing it eats and uncover that all food sources originate with plants.

Students have seen that as a plant grows, it takes nutrients from the soil, but at the time there was no attempt to discuss how soil is restored. In late elementary grades, students learn about forms of matter and life that are not visible to the unaided eye. This prepares students to understand that decomposers (including microbes) can break down the remains of dead plants and animals which recycles the nutrients trapped in those living organisms back to soils so that plants can continue to grow there. At this point, "microbes" describes organisms that are too small to be seen. Discussions that refer to cells (e.g., single-celled organisms) can wait until middle school.

Current (2018 Implementation): 4.LS2.1, 4.LS2.2, 4.LS2.3, 4.LS2.4

4.LS2.1 – Support an argument with evidence that plants get the materials they need for growth and reproduction chiefly through a process in which they use carbon dioxide from the air, water, and energy from the sun to produce sugars, plant materials, and waste (oxygen); and that this process is called photosynthesis.

Big Ideas:

Plants do not need to eat to grow because they can get the materials they need to grow from non-living parts of their environment.

Scientific Ideas:

- Plants have specific needs - water, air, sunlight, and nutrients.
- Plants depend on their surroundings for the things they need.
- Plants can take in the materials from their surroundings and use them to grow (make more plant material) and reproduce (make new plants).
- Materials plants need to grow and reproduce come from their physical environment, including air, water, and nutrients from the soil.
- Plants get their energy from the sun.

Common Student Ideas:

- Plants grow because their roots get food from the soil.
- …

4.LS2.2 – Develop models of terrestrial and aquatic food chains to describe the movement of energy among producers, herbivores, carnivores, omnivores, and decomposers.

Big Ideas:

If we trace the food sources for animals back to the source, then we find that all food starts with plants.

Scientific Ideas:

- Animals must eat to grow because food provides them with the materials they need to grow.
- Animals eat other animals and plants.

- Plants do not eat – they take matter directly from the air and soil.
- There will be a pattern in the type of food that a particular type of animal will eat - some animals eat only plants, other animals eat only other animals, and some animals eat both plants and animals.
- Some types of animals only eat the remains of things that used to be alive. These animals, including microbes, maintain and restore soil.
- Soils can become less "nutritious" for plants if nutrients are not restored.
- By observing animals in an ecosystem, we can figure out what they eat and create a "map" of this organization.
- The map of any ecosystem will lead back to a type of organism (usually plants) that does not eat other organisms and is able to take in matter another way.

Common Student Ideas:

- Food chains will have many links in them.
- Dead plants are a bad thing and should be removed from an ecosystem…

4.LS2.3 – Using information about the roles of organisms (producers, consumers, decomposers), evaluate how those roles in food chains are interconnected in a food web, and communicate how the organisms are continuously able to meet their needs in a stable food web.

Big Ideas:

A stable ecosystem has connections between many different types of organisms.

Scientific Ideas:

- Stable ecosystems are healthy.
- It is possible to map the connections between organisms in an ecosystem.
- If an ecosystem is stable, then it will eventually return to its prior state after a disturbance.
- A disturbance is an event that affects the ecosystem.
  - Disturbances can be the addition or removal of a species in an ecosystem.
  - Disturbances can also be the increase or decrease of a resource. (e.g., a tree falls and provides new areas of sunlight for plants and new habitat for organisms, more nutrients for decomposers.)
- Having more connections between organisms in an ecosystem means that disturbances are less likely to have significant effects on the different organisms in the ecosystem.
- Food chains allow scientists to track the sources of matter backwards through an ecosystem.
- Food webs allow scientists to visualize how the different types of organisms connect to each other in an ecosystem.

Common Student Ideas:

- Food chains and food webs communicate the same information.
- …

4.LS2.4 – Develop and use models to determine the effects of introducing a species to or removing a species from an ecosystem and how either one can damage the balance of an ecosystem.

Big Ideas:

The stability of an ecosystem depends on the interactions and roles of types of organisms that live there. Removing or adding a new species can change the roles and interactions and these changes can cause the ecosystem to become less healthy.

Scientific Ideas:

- Organisms have specific roles in their ecosystem (e.g., provide habitat, control the number of prey, recycle nutrients back into the ecosystem).
- Organisms may or may not be able to shift roles.
- The relationships between different types of organisms created.
- When an ecosystem loses a type of organism, the role that organism filled played may not be replaced immediately.
- New organisms can move into healthy ecosystems and compete with the organisms already established in the ecosystem.
- New organisms may have competitive advantages over existing organisms (e.g., seeds that sprout earlier and prevent sunlight from reaching other seedlings, have more larger numbers of young, and survive seasonal variations in temperature that cause other organisms to migrate or pass through a region.)
- As new types of organisms move into an ecosystem, they may cause changes that may hurt organisms that already lived in that ecosystem.

Common Student Ideas:

- An ecosystem is healthy if there are living things there.
- …

Revised (2025 Implementation): 4.LS2.1, 4.LS2.2, 4.LS2.3

4.LS2.1 – Develop and use models to illustrate the flow of matter through a food web/food chain beginning with sunlight and including producers, consumers, and decomposers.

4.LS2.2 – Using information about the roles of organisms (producers, consumers, decomposers) in an ecosystem, evaluate how those roles are interconnected in a food web, and communicate how the organisms are continuously able to meet their needs in a stable food web.

4.LS2.3 – Develop and use models to determine the effects of introducing a species to, or removing a species from, an ecosystem and how either one can damage the balance of an ecosystem.

6-8 Standards

By the end of grade 8. Organisms and populations of organisms are dependent on their environmental interactions both with other living things and with nonliving factors. Growth of organisms and populations increases are limited by access to resources, access to which consequently constraints their growth and reproduction. Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystem, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. – NRC, 2012

Progression Across Grade Bands

In elementary grades, students learn that there are connections between organisms because organisms of the ways that individuals meet their needs. For example, animals and plants are connected because many different animals eat plants, or that plants rely on microbes to replenish the soil they live in. Students learn that an ecosystem is a group of connected organisms and their environment. An ecosystem is defined by a set of relatively consistent interactions in a predictable environment. Any changes in either the type of organisms or the environmental conditions in an ecosystem will impact many things that live there.

The primary development in middle school is the introduction of populations, rather than just individuals. Students should learn that populations respond like organisms in many ways. The factors that impact the growth and development of individuals (LS1.B) also apply to populations – matter, energy, habitat, and interactions with other organisms. The availability of these factors can cause populations to grow quickly or slowly.

In early grades, students created system models for individuals. Some of the interactions that students may have identified also connect populations of organisms. Teaching students about specific types of interactions (e.g., mutualism, predatory) and then providing them examples to reinforce the interactions does not reflect the process of science. Instead, students can organize data on population sizes in an ecosystem to identify trends or patterns in the data. Students can describe the data patterns and identify proposed explanations for co-occurring shifts in population size. Students can then ask questions that would help them gather evidence to support their explanations through investigations or gathering information.

Current (2018 Implementation): 6.LS2.1, 6.LS2.2

6.LS2.1 – Evaluate the impact of environmental variables on population size.

Big Idea(s):

Populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.

Scientific Ideas:

- Ecosystems behave like large organisms and have the same needs as individual organisms.
- Organisms have needs for similar resources: food, water, and habitat.
- All resources have a finite amount.
- Because resources are finite, there will be competition.
- Increasing population sizes result in increased competition for shared resources.
- Changes to the number of available resources will also increase competition for shared resources.
- Change over time and changes to any biotic or abiotic factor in an ecosystem can lead to changes in all of its populations.
- Organisms have needs for similar resources: food, water, and habitat. The absence or abundance of any resource can impact a population.
- Increasing population sizes result in increased competition for resources.
- Competition may be between individuals of the same species or between different species.
- There is a natural tendency for populations to increase in size.
- Populations grow when organisms reproduce. Populations shrink when organisms die or move out of the ecosystem.
- Population size is constant when there is a balance between reproducing and dying/emigrating.
- The population size will continue to increase if there are sufficient resources.

Common Student Ideas:

- Competition between individuals always involves direct, aggressive action.
- Organisms of the same species do not compete for resources.
- Plants do not complete for resources.
- Plants do not compete for light.
- …

6.LS2.2 – Determine the impact of competitive, symbiotic, and predatory interactions in an ecosystem.

Big Idea(s):

Interactions between organisms within their ecosystem influence population sizes, and changes in one population may result in changes to a different population.

Scientific Ideas:

- Population sizes are influenced by the interactions of organisms within the ecosystem.
- How one population influences another depends upon the type of relationship between those two populations.
- On the scale of individual organisms, predation is negative for prey.
- At the scale of populations, predation is necessary to keep a balance between population size and available resources.
- Over short-term time scales mutualistic relationships benefit both organisms.
- Over generational time scales mutualistic relationships can become so interdependent that each organism requires the other for survival.
- When tightly connected mutualistic relationships develop, a decline in one population is likely to result in a decline of in the other population.
- Although the species involved in these different relationship types vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.
- Predators can decrease population sizes.
- While mutualistic relationships create a sort of interdependence where the two populations in a community move in tandem.
- Patterns of interaction are not limited to specific ecosystems; however mutually beneficial relationships are less common where resources are abundant.

Common Student Ideas:

- A change in the size of a predator population has no effect ondoes not affect the prey population.
- Predation is always a negative impact on the prey.
- Parasites always kill their host.
- A change in the size of a prey population has no effect ondoes not affect the predator population.
- If a population in a food web is disturbed, there will be little to no effect on populations that are not in the same linear sequence within the food web.
- Competition between organisms always involves direct, aggressive interaction.
- …

Revised (2025 Implementation): 6.LS2.1, 6.LS2.2

6.LS2.1 – Use data to evaluate and communicate the impact of environmental variables, both living and nonliving (e.g., food, water, oxygen, and other resources), on population size within a system.

6.LS2.2 – Construct an explanation that predicts patterns of competitive, symbiotic, and predatory interactions among organisms across ecosystems.

9-12 Standards

Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. Organisms could produce populations of great size were it not for the finite environments and resources. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. – NRC, 2012

Progression Across Grade Bands

Students have already recognized that organisms utilize resources provided by both living and non-living components of the ecosystem.

The new concepts that emerge in high school are the ideas of communities and carrying capacities in ecosystems. Ecosystems consist of communities of different populations that interact with each other and with the surroundings. The interactions that affect individual organisms also facilitate or limit the growth of populations and communities. The variety of interactions between organisms and their surroundings can limit the sizes of populations and communities.

Revised (2025 Implementation): Bio1.LS2.1

Bio1.LS2.1 – Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

Big Idea(s):

Interactions between biotic and abiotic factors serve as feedback mechanisms that limit the size of populations and communities in ecosystems.

Scientific Ideas:

- Living organisms meet their needs through interactions with each other and with their surroundings.
- Organisms can only survive in a limited range of conditions and in places that provide the resources that they need. Some physical factors that influence which organism can survive there include sunlight, temperatures, water, soil, space, etc.
- Organisms sometimes depend on specific interactions with other organisms.
- Organisms compete with other organisms for a limited pool of any resource.

- Negative feedback loops stabilize ecosystems by maintaining the carrying capacities of the ecosystem.
    - Competition for territory increases as population sizes increase. Territorial behavior can limit the number of organisms in a population.
    - As the number of populations grows in a community, there is increased opportunity for predators. Increased opportunity for predators limits the growth of populations.
- Carrying capacities can change. Positive feedback loops can destabilize ecosystems and cause changes to the carrying capacity of an ecosystem.
    - Changes to the amount of available space in an ecosystem can decrease the amount of production in the ecosystem which can reduce the carrying capacity of the ecosystem.

Common Student Ideas:

- Carrying capacity is a fixed quantity.

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

Guiding Question:

How do matter and energy move through an ecosystem?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to exploreing the way that matter and energy move into, out of, and through ecosystems.

CENTRAL IDEA(S)

Matter and energy transfer between living things and between living things and the physical environment. Transfers of matter happen at all scales and involve all phases of matter. Matter moves through organisms when one organism eats another organism, or when decomposers break down materials and return particles to the soil.
Energy enters ecosystems through plants or producers that capture energy, typically from the sun, and store it in chemicals that other living things can break down. Plants do not produce energy. The transfer of energy does not happen without matter.

GENERAL PROGRESSION

Grade Band	Scale of Materials	Movement of Materials
K-2	Visible materials (e.g., food, water, shelter.).	Some materials can be re-used by different organisms.
3-5	Visible materials, invisible materials (gases), and materials with internal structures (soils).	Matter cycles between organisms and their environment.
6-8	Atoms & Molecules	Atoms cycle between living and non-living parts of ecosystems.
9-12	Matter and Energy	Living systems use matter to store energy. Transfers of matter facilitate energy transfer.

In the earliest grades, students learn that organisms rely on each other and their surroundings to get things they need and that these things can be reused to meet the needs of more than one organism. When students learn that matter is made of particles, they can see that solids, liquids, and gases all move in and out of living systems. In middle school students learn about different elements and are able to see that there are cycles that allow different types of each element to cycle between living systems and the physical environment.

K-2 Standards

By the end of grade 2. Organisms obtain the materials they need to grow and survive from the environment. Many of these materials come from organisms and are used again by other organisms. – NRC, 2012

Progression Across Grade Bands

These standards set a foundation for the idea that plants capture all of the matter and energy for the system and that matter gets recycled in the ecosystem.

The objective for this grade band isf to help students see that the place where an organism lives provides materials that organisms use and that these many things are used repeatedly. Students are learning that plants need light and water to grow (LS1.C) and that they get the things they need from their surroundings (LS2.A). This component idea helps students see that some organisms get the things they need from other organisms – this sets a foundation for students to see plants as producers of all matter in an ecosystem. As it grows the tree can provide a place for a bird to build its nest. As time goes on, other organisms may use the materials as well. When a tree falls it may no longer be a place for birds to nest, but now insects and small animals can use the fallen tree for shelter. In this way, a single resource gets used multiple times.

In future grades, these early discussions about recycling of large, visible materials help students understand the way that microbes replenish soil by recycling nutrients back to into the soil. Students may be curious about decomposition. Exploring decomposition, such as composting, may allow students to see leaves becoming smaller bits of leaves that can then be recycled as mulch or to make new soil. There should be limits on conversations about decomposition. Students have not yet learned that matter can be broken down repeatedly until it is nothing more than small invisible particles, nor have they learned about cells and microbes.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): 1.LS2.3

1.LS2.3 – Develop and use models to show how plants and animals depend on their surroundings and other living things to meet their needs in the places they live.

3-5 Standards

By the end of grade 5. Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, water, and minerals from the environment and release waste matter (gas, liquid, or solid) back into the environment. – NRC, 2012

Progression Across Grade Bands

In earlier grades, students have seen that a single material (e.g., a fallen log) can serve different purposes for many organisms. Students should think about recycling on a different scale now that they know that matter is made of unseen particles.

Students learn about matter in this grade band, and the biggest idea for this progression is that matter, in all phases, moves back and forth between organisms and their physical surroundings during interactions.

Like many organisms, we eat solid food, drink water, and breathe air. Eating, drinking, and breathing are all interactions between us and our surroundings. We also release waste such as solids, liquids, and gases. Releasing waste is a process that returns matter to the physical environment.

Sometimes matter moves in forms that are too small for us to see and/or because of the activities of microbes – organisms too small to see without a microscope. Air is a collection of particles that are too small to see and very spread out. This understanding of air helps students understand that breathing is a way that matter moves between an organism and its physical environment. As students learn about microbes, they can understand that microbes such as those in our guts or in soils also produce gases which that can enter the atmosphere.

Discussions about life cycles reveal that all living things will eventually die. When this happens, the matter that they have accumulated during their lives will return to the physical environment. The goal is for students to consider the variety of exchanges that occur, not for students to memorize which materials exchange.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

6-8 Standards

By the end of grade 8. Food webs are models that demonstrate how matter and energy is transferred between producers (generally plants and other organisms that engage in photosynthesis), consumers, and decomposers as the three groups interact—primarily for food—within an ecosystem. Transfers of matter into and out of the physical environment occur at every level—for example, when molecules from food react with oxygen captured from the environment, the carbon dioxide and water thus produced are transferred back to the environment, and ultimately so are waste products, such as fecal material. Decomposers recycle nutrients from dead plants or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. – NRC, 2012

Progression Across Grade Bands

This progression began with students learning that organisms get things from their surroundings and that a single material can be used more than once. In late elementary school, students learn that all phases of matter cycle between living things and their surroundings as they interact. Energy is added to the progression in middle grades and students learn that matter is made of a limited set of atoms and these atoms cycle between organisms, each other, and their physical environment.

The key idea for middle school is that matter and energy transfers occur together during interactions between living things and each other or their surroundings.

Physical science standards help students understand that chemical reactions rearrange atoms. Some chemical reactions store energy in the materials that form. Other reactions produce chemicals that have less stored energy than the starting materials. This second group of reactions releases excess energy to the surroundings. It is helpful for students to experience these differences; Some reactions will warm up a container and others will cause it to cool depending on whether a particular reaction stores or releases energy. Firsthand experiences help students connect rearrangements of matter (chemical reactions) with transfers of energy (storing or releasing chemical energy).

Students should understand that the compounds made during photosynthesis only form when an external energy source is available. Plants and some other organisms can gather this required energy from the sun. Photosynthesis reactions store energy in the sugars that for form during the reactions.

Photosynthesis accounts for the transfers of energy and matter into living systems. Food webs are models that provide a way to understand how interactions among living things transfer matter and energy. Food webs do not account for transfers of matter and energy between living things and their physical environment.

Soils are a critical place where matter transfer occurs between living things and their physical environment. Students should think of soil (dirt) as a collection of particles - gases, water, microbes, minerals (particles from broken down rocks), and decomposing organic matter. Plants interact with the soil and grow as their roots gather minerals from the soil. Eating is an interaction that brings matter from prey to predator or from producer to consumer. When an organism dies, microbes break down its body and the minerals become part of the soil again.

There is a limited supply of different elements/compounds in every ecosystem. A stable ecosystem recycles these materials.

Current (2018 Implementation): 6.LS2.3, 7.LS2.1

6.LS2.3 – Draw conclusions about the transfer of energy through a food web and energy pyramid in an ecosystem.

Big Idea:

Matter cycles between the living and non-living components of an ecosystem and facilitates the transfer of energy into, within, and out of ecosystems.

Scientific Ideas:

- Food is made of (atoms) and contains stored chemical energy.
- The arrangement of atoms changes during a chemical reaction.
- The rearrangement of atoms can store energy or can release energy depending on the amount of energy in the starting materials relative to the amount of energy in the end products.
- The atoms in food are rearranged inside the bodies of organisms, resulting in a release of energy.
- Some of the energy released from food allows the organism to complete tasks necessary to sustain life.
- Energy is transferred between producers, consumers, and decomposers in an ecosystem.
- The transfer of energy into an ecosystem is accompanied by the transfer of matter. This matter can come from the non-living parts of the ecosystem.
- Consumers combine the food with oxygen, permitting the use of stored energy and matter for growth.
- One organism uses, on average, 90% of the energy it consumes. The remaining 10% can be passed on to further consumers or decomposers.

Example(s) of Common Student Ideas:

- Energy pyramids show the number of organisms in each trophic level.

- Energy pyramids get narrower moving towards higher levels because there are less of the large consumers in the ecosystem.

7.LS2.1 – Develop a model to depict the cycling of matter, including carbon and oxygen, including the flow of energy among biotic and abiotic parts of an ecosystem.

Big Idea:

Atoms of carbon and oxygen move between living and non-living parts of an ecosystem in tandem with transfers of energy through living systems.

Scientific Ideas:

- Matter is made of atoms and contains stored chemical energy.
- When organisms eat, they take matter into their bodies.
- Some of the matter that an organism consumes gets digested and becomes part of their body and some of the matter that an organism consumes will pass through their body as waste.
- Organisms use oxygen from the environment in a chemical reaction that rearranges the atoms in food and releases energy from the food.
- When food is broken down, the carbon contained in the food becomes part of CO_2 and returns to the environment.
- Plants can store energy from the sun in a carbon-based sugar that required requires an input of CO_2 from the environment to make.
- Plants release oxygen as a waste product from the reactions that capture energy from the sun and produce sugars.

Example(s) of Common Student Ideas:

- There is no limit to the forms of matter needed for living systems because the atoms are so small and so common on Earth.
- Living things can use all forms of an element in the environment (e.g., CO vs CO_2)

Revised (2025 Implementation): 6.LS2.3, 7.LS2.1

6.LS2.3 – Use a model to construct an explanation about the transfer of energy through a food web and energy pyramid in an ecosystem.

7.LS2.1 – Develop a model to depict the cycling of matter, including carbon and oxygen, and the flow of energy among biotic and abiotic parts of an ecosystem.

9-12 Standards

Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain.

The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. Competition among species is ultimately competition for the matter and energy needed for life.

Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
– NRC, 2012

Progression Across Grade Bands

This progression begins before students learn about energy or even a formal definition of matter. At that time, students learn that organisms use materials from their surroundings, and importantly the idea that the materials from one organism get used by other organisms. Students learn to view the recycling of matter at smaller scales as they learn about the worlds of microbes and microscopic particles.

Middle school Sstudents learn that matter can store energy in middle school – any changes in matter also require changes in energy. This allows students to understand that when light or another energy source is present, plants or other producers can capture energy from alternate sources and perform reactions that build sugars and bind this energy. Separate sets of reactions can release the energy stored in sugar.

Producers create a limited amount of energy stored in matter and all other organisms in an ecosystem depend on this energy. The largest portion of the matter that an organism consumes passes through their bodiesits body as waste. The matter that passes through an organism without being broken down retains its stored chemical energy and provides both matter and energy for decomposers. The matter that organisms consume can be used to drive chemical reactions or to build materials that organisms need for growth through cell division. The limited pool of energy and matter captured by producers and the inefficiencies of energy transfer and use limit the size of ecosystems.

Revised (2025 Implementation): Bio1.LS2.2

Bio1.LS2.2 – Create, or use, a mathematical model to describe the transfer of energy from one trophic level to another. Explain how the transfer of energy transfer between trophic levels affects the relative number of organisms that can be supported at each trophic level and necessitates a constant input of energy from sunlight and inorganic compounds from the environment.

Big Idea(s):

All organisms in an ecosystem compete for a limited pool of energy supplied by producers who capture energy from the Sunlight or a few inorganic compounds. All energy transfers between organisms happen through the transfers of matter.

Scientific Ideas:

- All organisms are made of cells. The growth of an organism occurs as cells obtain matter and use it to produce more cells.
- *Energy is involved whenever matter changes:* – Sets of chemical reactions inside of cells create the larger carbon-based molecules that organisms use to build more cellular materials. Chemical reactions that build larger carbon-based molecules require an energy input.
- *Organisms use energy for multiple purposes:* – In their daily activities, organisms might also convert stored chemical energy into other forms of energy by doing mechanical work. For example, this includes the work done when animals move around or move other objects around.
- *Organisms use matter for multiple purposes:* – Energy transfers between organisms in an ecosystem occur through transfers of matter. A portion of the matter that transfers between tropic levels provides the materials needed for the growth of organisms – through the construction of cellular materials. Another portion of the matter provides the stored chemical energy needed to construct those cellular materials.
- *Large organisms are inefficient consumers:.* Organisms only capture a small portion of the matter from the food they eat. Most of the food an organism consumes gets released back into the environment. Due to this inefficiency, organisms must consume far more matter than they successfully capture for metabolism.
- *Decomposers receive energy from all trophic levels:.* Other communities of organisms such as decomposers compete for the unprocessed matter released by larger organisms and use it for their own growth and energy production.

- *Organisms must obtain far more matter than they are able to use directly for growth:.* Since the matter that organisms consume must serve two purposes (the physical materials for growth and the stored energy for growth), yet each unit of matter can serve only one of these purposes.
- *Each successive tropic level requires a significantly larger pool of matter from lower levels:.* The combined inefficiencies of consumers (in the harvesting of matter and the use of matter for growth) compound across all the organisms at a given trophic level.
- *All other organisms compete for a limited pool of matter and therefore energy generated by producers:.* Producers generate the pool of matter, and therefore energy, available for the growth of an ecosystem. All other organisms compete for this same limited pool of matter and energy.
- *The amount of matter and inefficiencies in the transfer and use of matter constrain the size of ecosystems:*. These constraints limit the size of populations and the number of trophic levels in the ecosystem.
- *Alternate energy generations pathways still depend on a source of carbon from their surroundings:*. Producers who do not obtain energy from the Sun use pathways that can transfer chemical energy stored in inorganic compounds into molecules of glucose.

Example(s) of Common Student Ideas:

- Energy and matter are independent cycles in ecosystems.
- Organisms grow by directly using the materials they consume as food.
- Consumers capture most of the useful materials from the food they eat during digestion.

All the energy that leaves a system at a given trophic level is a result of the generation of heat and moving around.

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Guiding Question:

What happens to ecosystems when the environment changes?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to consider how changes to different places can affect the characteristics of that place and interactions among the organism that live there.

CENTRAL IDEA(S)

The places where organisms live will change. Changes can be sudden or gradual – and may affect the temperatures, availability of sunlight, availability of water, availability of food, etc. Changes can affect the types of organisms that can live in a place which can then affect the resources and services derived from that organism. Stable ecosystems are able to cope with certain amounts of change. Biodiversity is an indicator of the health of an ecosystem.

GENERAL PROGRESSION

Grade Band	Scale of System	Nature of Change (outcome)
K-2	Plants and animals in schoolyard and neighborhood.	Too hot/cold, too wet or dry, not enough food. (Plants and animals may not survive.)
3-5	Living things in any environment.	Physical characteristics, temperature, resource availability. (Organisms may move somewhere else, move in to that place, and may not survive and reproduce.)
6-8	Populations in ecosystems.	Physical components or biological components. (Populations may grow, shrink, move in, move out, or become extinct.)
9-12	Ecosystems.	Any disturbance. (Ecosystems may or may not be resilient.)

This progression begins by looking at simple ways that local places can change and how these changes create conditions that some organisms may not be able to survive. In late elementary, students consider a range of responses by organisms and how an ecosystem might look different depending on how different types of organisms respond to the changes. The ideas of stability and biodiversity appear in middle school as students consider that some changes can be cyclic and that a stable ecosystem copes with disturbances.

K-2 Standards

By the end of grade 2. The places where plants and animals live often change, sometimes slowly and sometimes rapidly. When animals and plants get too hot or too cold, they may die. If they cannot find enough food, water, or air, they may die. – NRC, 2012

Progression Across Grade Bands

Ecosystems consist of the physical conditions in a certain place, the organisms that live in that place, and the interactions among organisms and their physical surroundings. The first idea for this progression is that a place can change and that some changes are fast, and others are slow.

The main objective for this grade band is for students to see that some organisms will not survive when the place where they live changes. Changes can cause places to become too hot/cold, too wet/dry, or make it too hard for organisms to find the resources they need – food, and water.

Students should consider changes to places that are local and accessible (e.g., shade disappears when a tree falls or a place may become dry and shaded as a tree grows and matures, an empty lot or lawn may become dry after a long period without rain). Places also change across seasons – sometimes it can become too hot in the summer or too cold in the winter. Organisms will not survive if they cannot get the things they need or if the conditions change too greatly. For example, a sudden drop in winter temperatures can kill plants or students may see that the types of grass and weeds in their school fields change as the temperature changes.

Students may already be aware that some animals have behavioral adaptations, such as migration or hibernation, which help them survive. Behavioral adaptations are addressed in later grades. Limit discussions in the earliest grades to the idea that some organisms will not survive the changes to the place where they live.

Current (2018 Implementation): 2.LS2.2

2.LS2.2 – Predict what happens to animals when the environment changes (temperature, cutting down trees, wildfires, pollution, salinity, drought, land preservation).

<u>Big Idea:</u>

The places where animals live will change, and these changes can impact the animals that live there.

<u>Scientific Ideas:</u>

- Living organisms have individual needs.
- Many types of organisms meet their needs in specific ways that do not change easily.
- Living organisms rely on each other and on the place where they live to get the things they need to survive.
- Places can change in different ways – quickly, slowly, isolated events, and cyclic changes.
- As a place changes, the conditions in that place may become hotter/colder, warmer/drier, sunnier/shadier, saltier/less salty, more accessible/less accessible, etc.
- Living things only survive in a certain range of conditions.
- If living things cannot get the things that they need from their environment, they will die.

Common Student Ideas:

- As long as there are plants growing somewhere, then organisms will have food to eat.
- All changes are sudden and easily observable.

Revised (2025 Implementation): 2.LS2.2

2.LS2.2 – Predict what happens to animals when the environment changes (e.g., temperature, cutting down trees, wildfires, pollution, salinity, drought, land preservation).

3-5 Standards

By the end of grade 5. When the environment changes in ways that affect a place's physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die. – NRC, 2012

Progression Across Grade Bands

This progression began by looking at the ways that a place can change in ways that create conditions where some organisms can no longer survive there. In this grade band, students consider a range of responses by organisms that change the interactions within the ecosystem – some organisms may survive and reproduce, other organisms may be able to move out of the area, and some organisms may move into the area.

Students may have previously considered how a place changes when a tree falls or is removed. The absence of the tree may bring additional sunlight to a place that had been cool and shaded before. Some plants that needed a cool shaded place may have turned crispy and died. In this grade band students should also consider that the light and warmth may allow new species, such as grasses, to move into the area. Grasses may not provide the same food or shelter that insects depended on and may leave the area as grasses replace the original plants. The key idea is to observe or think about how a place changes, by observing the ways that a variety of interactions might change. If students have mapped the organisms and interactions at a place, then it will be easier for them to see the chain of effects that may occur.

Many organisms have life cycles that are linked to environmental conditions. When the environment changes the life cycle of the organism may no longer align with its physical environment. For example, early warm springs may cause seeds to germinate only to be killed during late frosts. This may disrupt other organisms that depend on these seed sources.

In middle school, students will discuss entire populations and the idea of ecosystem stability. Students also consider that some of the benefits of an ecosystem are tied to the organisms that live there. Changes to the populations of organisms will impact the resources and services provided by those organisms. Ecosystem changes may lead to extinction of species. The idea that some organisms will survive and reproduce in a changed environment supports understanding adaptation in later grades.

Current (2018 Implementation): 4.LS2.5

4.LS2.5 – Analyze and interpret data about changes (land characteristics, water distribution, temperature, food, and other organisms) in the environment and describe what mechanisms organisms can use to affect their ability to survive and reproduce.

Big Ideas:

Organisms rely on their surroundings to meet their needs and when the place that they live changes, there are typical outcomes for the way that organisms cope with the changes.

Scientific Ideas:

- Each type of living organism has a relatively specific set of needs that they it must meet in order to survive.
- Organisms get food, water, air, and shelter from other living things and from their environment.
- There are many different types of changes that can happen to a place – fast and slow, cyclic and isolated events, and large scale and small scale.
- Some changes occur but may not affect organisms if the change does not impact the physical characteristics of a place or the resources of that place.
- When a change to a place impacts the characteristics of a place (e.g., the amount of sunlight reaching a spot on the ground) or the availability of resources in a place (e.g., the amount of rainfall in an area) the change will affect some of the organisms that live there.
- Some organisms can find new ways to meet their needs when a place changes.
- Some organisms will no longer be able to meet their needs when a place changes and there are several possible outcomes for these organisms.
    - The organisms may leave the place they once lived.
    - The organisms may die when they cannot meet their needs.
- Some changes may create opportunities for new organisms to move into a place where its their needs could not have been met before. (e.g., a fallen tree provides new shelter for some animals, a new food source for others, and allows more sunlight to reach the ground.)
- It takes many generations for adaptations to become common in a type of organisms.

Common Student Ideas:

- Changes must happen on a large scale (e.g., large geographic areas) to affect living things.
- All changes to the environment are caused by people and can be eliminated if people are more careful.
- Individual organisms can adapt to the changes to in their environment.
- Organisms only respond to sudden changes or significant events and these outcomes do not occur when things happen slowly or in cycles.
- Once an organism has left a place, it will not move back to that place.

Revised (2025 Implementation): 4.LS2.4

4.LS2.4 – Analyze and interpret data about changes in the environment to explain how some organisms may survive and reproduce, some may not survive, others move to new locations, yet others move into the transformed environment.

6-8 Standards

By the end of grade 8. Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all of its populations. Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. – NRC, 2012

Progression Across Grade Bands

Students have considered how a place can change. In the earliest grades, students saw that changes might create conditions where some organisms could not survive. In late elementary school, students saw a greater range of possibilities when a place changes – organisms may move away from a place, new organisms may move into the place, and some organisms may survive and reproduce in that place. In the middle grades, students view ecosystems over time and consider factors that create stability in an ecosystem.

Change and stability are separate concepts; Even stable ecosystems change. For example, seasonal changes in temperature can affect available resources as some plants enter dormancy. This may cause entire populations of organisms to migrate from a particular ecosystem, yet these populations may return to the area as temperatures change and food sources become available.

There are limits to the amount of change that stable ecosystems can endure. If temperature changes occur too quickly or deviate too far from typical changes, then some organisms that are critical to the stability of an ecosystem may not survive.

Biodiversity accounts for the number of different organisms living in a place and is one factor that creates stability in an ecosystem. Disturbances to an ecosystem can have a significant effect on a particular population in that ecosystem. In healthy ecosystems, other species can offset the effects on one species. In ecosystems where a particular population is disproportionately large (lower biodiversity), there may not be other species able to replace the function of the affected species and the scale of the negative effects may be greater.

Current (2018 Implementation): 6.LS2.4, 6.LS2.5, 6.LS2.6

6.LS2.4 – Using evidence from climate data, draw conclusions about the patterns of abiotic and biotic factors in different biomes, specifically the tundra, taiga, deciduous forest, desert, grassland, rainforest, marine, and freshwater ecosystems.

<u>Big Idea(s):</u>

Global patterns in climate and resources create patterns in the distribution of different types of biomes.

Scientific Ideas:

- Biomes and ecosystems are characterized by specific conditions that determine which types of species will thrive there.
- There is a range in the conditions of certain types of ecosystems.
- Biodiversity reflects the number and different types of organisms that live in an area.
- Different ecosystems have different levels of biodiversity.
- Biodiversity is a measure of the health of an ecosystem.
- A healthy ecosystem (high biodiversity) is more likely to buffer out a disturbance.
- Each different type of biome has a particular species (keystone) that provides a service or resource that supports many other species in the ecosystem.

Common Student Ideas:

- For any given biome, the same species will be found there (e.g., rainforests).
- Ecosystems are healthy as long as the physical space is preserved.
- The places where people live are not parts of ecosystems.

6.LS2.5 – Analyze existing evidence about the effect of a specific invasive species on native populations in Tennessee and design a solution to mitigate its impact.

Big Idea(s):

An ecosystem can change when a new species enters the ecosystem and outcompetes the organisms already established there.

Scientific Ideas:

- Organisms have specific needs that must be met, and all members of a particular species have similar needs and similar ways to meet their needs.
- An ecosystem is a collection of living organisms and non-living characteristics/resources and the interactions among organisms and their environment.
- It is possible to monitor the health of an ecosystem by observing the variety of organisms that live there, the interaction between these organisms, and the interaction between the organisms and their place.
- Organisms will reproduce when their needs are met and therefore populations can get larger.
- There are limited resources in an area and organisms with similar needs will compete for shared resources.
- The ecosystem can change in ways that may allow a new species to move/be moved into the area.

- Introducing a new species will create more competition for shared resources.
- New species can enter into a stable ecosystem and may have an advantage that allows them to outcompete the organisms already present in the area.
- A new species may not have a predator/herbivore in an ecosystem that will control its population size.
- An invasive species is another type of disturbance that will have an effect onaffect the health of an ecosystem.
- Solutions designed to control invasive species will have unintended consequences as well as anticipated trade-offs that should be considered when planning a strategy to control an invasive species.

Common Student Ideas:

- Any introduced species will become an invasive species.
- An ecosystem is healthy as long as things are living there.
- …

6.LS2.6 – Research the ways in which an ecosystem has changed over time in response to changes in physical conditions, population balances, human interactions, and natural catastrophes.

Big Idea(s):

Ecosystems are dynamic collections of populations that can be impacted by external pressures.

Scientific Ideas:

- Ecosystems are collections of different types of organisms.
- The types of organisms in an ecosystem are a result of physical conditions and the history of that place.
- The members of different populations of organisms in an ecosystem will interact in consistent ways.
- Human activities and growth of human populations will impact the ecosystem they are part of.
- Changes to the available resources for an ecosystem will influence the populations that live there.
- Changes in the size of one population will often result in a change to the size of other populations.
- Natural catastrophes have the potential to impact many populations all at once.
- As an ecosystem recovers from a natural catastrophe, the new ecosystem may look different from the ecosystem that existed previously.

Common Student Ideas:

- Humans are not part of an ecosystem.
- ...

Revised (2025 Implementation): 6.LS2.4, 6.LS2.5

6.LS2.4 - Construct an explanation that uses abiotic (e.g., precipitation, temperature, soil) and biotic (e.g., biodiversity, number of organisms) patterns in earth's terrestrial and aquatic ecosystems (e.g., tundra, taiga, deciduous forest, desert, grasslands, rainforest, marine, and freshwater) as measures of ecosystem health.

6.LS2.5 - Analyze existing evidence about the effect of a specific invasive species on native populations in Tennessee and design a solution to mitigate its impact.

9-12 Standards

A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

– NRC, 2012

Progression Across Grade Bands

Places can change in a variety of ways that may affect the conditions or resources in that place. Organisms may not be able to survive in the changed environment. However, changes may not necessarily wipe out all organisms as some may survive, while others may leave the place and change may provide an opportunity for new organisms to move into the place. Ecosystems are made of populations.

An ecosystem consists of interactions between living and non-living components. Organisms compete for a limited pool of resources, including a limited supply of matter and energy generated by producers. The competition for matter and energy generates a variety of types of interactions that produce a relatively stable ecosystem.

A stable ecosystem is one in which the varying species in that ecosystem interact in consistent ways that support their relative population sizes. When a stable ecosystem experiences a relatively small disturbance, there may be a temporary shift in population sizes, but ultimately the ecosystem returns to the way that it was before. When a stable ecosystem experiences a small disturbance, there may be a temporary shift in population sizes, but the ecosystem returns to the way it was before. Major disturbances change ecosystems to degrees where the collections of populations that is are established in the recovered ecosystem are different than the original populations. This can lead to species extinctions.

Revised (2025 Implementation): Bio1.LS2.3, Bio1.LS2.4

Bio1.LS2.3 – Obtain, evaluate, and communicate information based on evidence to describe how the impact of varying levels of disturbance is related to the resilience of an ecosystem.

Big Idea(s):

A resilient ecosystem is one whose interactions can persist despite disturbances. However, the intensity of a disturbance can vary, and ecosystems may be greatly changed in ways that some species may not survive.

Scientific Ideas:

- Every different type of organism can survive under a certain range of conditions. When conditions are too hot or too cold, too wet or too dry, etc., some organisms will not survive.
- Changes in an environment can lead to conditions that suit different populations. When a place changes, some organisms will survive, some will move out of the area, and new species may move in, and some may not survive.
- Populations will increase in number if they have access to necessary resources, including matter and energy. Populations will increase if they have access to necessary resources, including matter and energy. Population size is limited by resource availability and external pressures.
- The competition for matter and energy causes a variety of interactions between populations. The size of populations in the ecosystem is limited, supported, and maintained by interactions with other populations.
- If the conditions in a place are consistent over an extended period, then interactions between populations will regulate the size of each population creating a stable ecosystem.
- Disturbances can be gradual such as habitat loss due to more frequent flooding, or disease. Some disturbances can occur suddenly, such as forest fires.
- Disturbances can be caused by biological factors, such as invasive species or disease, or physical agents, such as habitat loss, or changes to the climate.
- The connected nature of populations in an ecosystem means that significant changes to any one population can have effects on the entire ecosystem.
- Changes disrupt an entire ecosystem. When this happens, a new ecosystem will ultimately establish itself in that place, but this may occur at the loss of one or many species.

Common Student Ideas:

- An ecosystem is a place.
- Extinction only happens in sudden disasters.
- Extinction only happens due to over hunting.
- An ecosystem is stable as long as there are many organisms living there.An ecosystem is stable if there are many organisms living there.

Bio1.LS2.4 – Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Big Idea(s):

Human activity can be beneficial and harmful to ecosystems. Any solution will have both positive and negative impacts. By defining the criteria and constraints for design tasks, engineers can establish priorities that will help identify optimal solutions.

Scientific Ideas:

- Ecosystems have living and non-living components.
- Organisms depend noon both living and non-living components from their surroundings.
- Changes to non-living components in an ecosystem impact the organisms living there.
- Actions by living things cause changes to their surroundings.
- Organisms compete for a shared and limited set of resources. Changes in one population size will have effects on other populations.
- As human populations grow, they use more resources.
- Technologies that allow humans to live more comfortably can also increase the impacts humans have on their environments.
- Over time, improvements in these technologies, such as new materials, can decrease the impacts of these technologies.

Common Student Ideas:

- Manmade materials do not depend on resources from the environment.

LS2.D: Social Interactions and Group Behavior

Guiding Question:

How do organisms interact in groups so as to benefit individuals?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to help students understand how groups of the same species help individuals meet their needs.

CENTRAL IDEA(S)

Individual organisms benefit from being part of a group. Groups can take a variety of structures which may distribute work to different members. Groups can be dynamic. Some organisms have developed such strong needs for group affiliation that individuals can suffer when they are not part of a group.

GENERAL PROGRESSION

Grade Band	Understanding of Groups
K-2	Group definition and benefits of group belonging
3-5	Group dynamics (composition, roles, hierarchies)
6-8	Group formation, communication, and dissolution
9-12	Group affiliation and necessity in social animals

The LS2 set of disciplinary core ideas is about ecosystems and interactions. This component idea is about organisms that form groups with other organisms of the same type. This is different from LS2.a A, which includes interactions between organisms but focused focuses on interactions between different types of organisms at an ecosystem level – e.g., predation, mutualism, competition.

Individual organisms are generally more likely to survive when they are part of a group. Over generations, group behaviors have become engrained due to the pattern of increased survival rates for individuals living in groups. The characteristics of different groups can change over time. Being part of a group is a need for social animals and their health depends on having a sense of belonging.

K-2 Standards

By the end of grade 2. Being part of a group helps animals obtain food, defend themselves, and cope with changes. Groups may serve different functions and vary dramatically in size. – NRC, 2012

Progression Across Grade Bands

This progression should begin with students identifying ways that animals work together. Ideally, students should have the opportunity to discuss examples from organisms they may have seen before. This can include animals looking together to obtain food. Examples could include ants that establish trails towards food, bees that signal the location of food sources, various predators that hunt in packs, etc.

Organisms also work together to defend themselves. This could include groups of birds that take flight all at once in a way that makes an individual bird difficult to track, deer using their tails to signal danger, etc.

Later in elementary school, students address that groups have internal structures and/or hierarchies. Ideas about hierarchies within groups, such as the structure of a colony of bees, are discussed in later grades.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Groups can be collections of equal individuals, hierarchies with dominant members, small families, groups of single or mixed gender, or groups composed of individuals similar in age. Some groups are stable over long periods of time; others are fluid, with members moving in and out. Some groups assign specialized tasks to each member; in others, all members perform the same or a similar range of functions. – NRC, 2012

Progression Across Grade Bands

Although there are ideas for earlier grade bands, there are not no earlier standards in this progression. Students may have observed organisms, such as ants and bees, which work together. Organization at levels that are not visible is a theme across all disciplines in this grade band. Groups have a variety of organizational structures.

Learning in this grade band should address the internal dynamics of the group. The dynamics of groups include the composition of groups, the ways that groups can change over time, hierarchies within groups, and structures within groups that divide up tasks.

In middle grades, the idea of stability is central to discussions about groups, just as it is the central idea for ecosystems. Students will consider how groups form.

Current (2018 Implementation): 3.LS2.1

3.LS2.1 – Construct an argument to explain why some animals benefit from forming groups.

Big Ideas:

There is variation in the size, structure, and organization of animal groups, but they always form because the group is beneficial to its individual members.

Scientific Ideas:

- A group is a collection of organisms that are all the same type.
- Being part of a group benefits individual members (e.g., capturing food, protecting young, confusing predators).
- Groups can have different structures – equal individuals, hierarchies.
- There are many different sizes of groups.
- Groups can be static where members remain part of the group for a long period of time or fluid where members move in or out.
- Some groups have specific and different roles for their members, while other groups have similar responsibilities.

Common Student Ideas:

- All living things form groups.
- …

Revised (2025 Implementation): 3.LS2.1

3.LS2.1 - Obtain information to compare various ways that groups organize (e.g., specialized roles for members vs same roles for members) to explain the benefits of animal group behavior.

6-8 Standards

By the end of grade 8. Groups may form because of genetic relatedness, physical proximity, or other recognition mechanisms (which may be species- specific). They engage in a variety of signaling behaviors to maintain the group's integrity or to warn of threats. Groups often dissolve if they no longer function to meet individuals' needs, if dominant members lose their place, or if other key members are removed from the group through death, predation, or exclusion by other members. – NRC, 2012

Progression Across Grade Bands

Students first learned that groups are helpful to individuals and then learned that groups look different. Students should be aware that groups have many hierarchies, that individuals in the group may have specific roles, and that groups can have a variety of compositions. In elementary school, it is treated as a given that the group exists and then there may be factors that cause the size of the group to fluctuate.

The middle grades progression adds communication between individuals to the discussion of groups. Communication includes both verbal and non-verbal communication. Communication between individuals helps the group form and helps coordinate actions among members of the group. Basic communication between individuals is a precursor to social behavior which is the major development in high school standards.

Current (2018 Implementation): 6.LS2.7

6.LS2.7 – Compare and contrast auditory and visual methods of communication among organisms to survival strategies of a population.

Big Idea(s):

Communication within a group is beneficial to the individual members of the group.

Scientific Ideas:

- Individuals are more likely to survive when they are part of a group.
- In nature, groups form because of the behaviors of individuals.
- Forming groups that nurture young and pass along knowledge increases the probability that a population or species will survive.
- Communication can serve a variety of purposes for groups (e.g., recognition, warning) maintaining connections within members.
- Humans engage in visual and auditory communication that serves the same purposes.

Common Student Ideas:

- All communication between organisms of the same species serves only one purpose (e.g., birds only chirp to attract a mate).
- Animals only communicate with organisms in their own species.
- …

Revised (2025 Implementation): No Standard

9-12 Standards

Animals, including humans, have a strong drive for social affiliation with members of their own species and will suffer, behaviorally as well as physiologically, if reared in isolation, even if all of their physical needs are met. Some forms of affiliation arise from the bonds between offspring and parents. Other groups form among peers. Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. – NRC, 2012

Progression Across Grade Bands

Students have already explored the ways that organisms benefit from group membership as well as various characteristics of groups, including group structures, dynamics, roles, and the formation, communication within and dissolution of groups. Students have explored the ways that organisms benefit from group membership and various characteristics of groups, including structures, dynamics, roles, and the formation, communication within and dissolution of groups. In high school, discussions about a group's membership consider the idea of group belonging.

Group behaviors are beneficial, and natural selection will favor certain behaviors. For example, when a mother guards its her nest and protects its her offspring from predators, their her offspring are more likely to survive. Over time, nest- guarding behaviors will become more common in a population. In this way, selective pressure has deeply engrained a need for group affiliation in individuals, – including chemical pathways and positive feedback loops that encourage group belonging.

Group membership has become so established in some species that relationships and connections with others have become a basic need for individuals. In the same way that food and water are basic needs, fulfilling the desire to connect to others is essential to development. This is a different perspective on groups than the ideas of earlier grades where group membership served basic functions such as warning when predators were nearby.

Revised (2025 Implementation): Bio1.LS2.5

Bio1.LS2.5 – Analyze data about the role of group behavior on individuals' and species' chances to survive and reproduce.

Big Idea(s):

Group behavior is beneficial to individuals. The tendency to form groups for some species has persisted for so many generations that the behaviors have become a basic need for individuals.

Scientific Ideas:

- Groups serve a variety of functions with many different structures. Being a part of a group increases the likelihood that an individual will survive.
- Groups' advantages are often due to the altruistic behaviors of individuals – members of a group make individual sacrifices for the benefit of the larger group. For example, warning calls reveal an individual's hiding place, but alert the group about a nearby predator.
- Groups are more likely to stay together when the benefits of membership outweigh the costs.
- The behavior of organisms depends on genetic factors and learned experiences. Genes that support group belonging increase the likelihood that an organism will survive. Over time, these genes will become more common in a population.
- Group belonging has increased survival rates for individuals over many generations. The result has been the selection for of genes that support group belonging. Many of the behaviors now have connections within an organism's DNA, for example, the expression of genes involved in the production of oxytocin in mammals.
- Positive selection for group- forming behaviors in sexually reproducing species increased the likelihood that a particular species avoids extinction by keeping members close together.
- The genomes of some species have developed over generations to include genes that encourage group membership. The development of organisms with a drive towards social affiliation is negatively impacted if these individuals do not experience connections with others.

<u>Common Student Ideas:</u>

- Being part of a group eliminates individual risk.
- All members of a group will benefit from membership.
- Genes only impact the physical characteristics of organisms.
- Natural selection only applies to the physical features of individuals and not to behaviors.

LS3.A: Inheritance of Traits

Guiding Questions:

How are characteristics of one generation passed to the next?
How can individuals of the same species and even siblings have different characteristics?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to explain why organisms look similar to their parents because of inheritance, and that differences between in the characteristics in parent and offspring can be explained by interactions with the environment and the role of DNA (genes).

CENTRAL IDEA(S)

Organisms carry out chemical reactions that produce proteins using genetic information stored in their DNA. Proteins control the activities of cells, and ultimately many of an organism's characteristics. Interactions with the environment, the combination of a portion of each parent's genes during fertilization, and occasionally to random mutations all help explain differences in the appearance and behaviors between parents and offspring.

GENERAL PROGRESSION

Grade Band	Features Compared Between Parent(s) and Offspring
K-2	Similarities and differences in visible, external features.
3-5	Similarities and differences in visible, external features, growth, and behavior due to inheritance or environment.
6-8	Similarities and differences due to the transfer of genes (alleles).
9-12	Similarities and differences due to expression- regulated genes in DNA.

The progression begins by introducing the concept of "characteristics," where students uncover the pattern that organisms look more like their parents compared to unrelated organisms of the same type. In late elementary school, students focus on differences between parents and offspring and learn that some differences caused by the environment and will not follow patterns of inheritance. In middle school, students learn that cells contain genes and that genes encode instructions to produce proteins. Students learn to account for similarities and differences between an organism and its parents that arise from the way genes combine during sexual reproduction.

K-2 Standards

By the end of grade 2. Organisms have characteristics that can be similar or different. Young animals are very much, but not exactly, like their parents and resemble other animals of the same kind. Plants also are very much, but not exactly, like their parents and resemble other plants of the same kind. – NRC, 2012

Progression Across Grade Bands

This component idea begins by introducing the idea of characteristics. In the earliest grades, discussions should be limited to characteristics that are visible. One way to introduce this topic would be to allow students to add descriptions of a group of organisms to a word wall. For example, in a group of dogs, students may see brown fur, black fur, tan fur, white fur, etc. Compiling these descriptions is a way to introduce “fur color” as a characteristic. Students could also collect samples such as leaves or bark rubbings from around the campus. This might reveal characteristics like leaf shape, patterns in the veins of a leaf, arrangement of the leaves on the stem.

Once students understand the concept of characteristics, they can make comparisons between parents and offspring. This component idea is about inheritance, so comparisons should always include parents and direct offspring. Students should compare organisms of the same type; for example, looking for similarities between a young puppy and its parents compared to another puppy that has different parents. This example allows students to look past features like having four legs and to notice smaller details. Students should also observe differences between a parent and offspring. A list of similarities and differences should reveal more similarities and less fewer differences in offspring when compared to an unrelated organism.

A separate discussion is about the ways that organisms of the same type have similarities in their appearance and this discussion of variation within a species is part of component idea LS3.bB.

Students should uncover the similarities between parents and offspring in early grades to prepare for the introduction of the law of inheritance later in elementary school.

Current (2018 Implementation): K.LS3.1

K.LS3.1 – Make observations to describe that young plants and animals resemble their parents.

<u>Big Ideas:</u>

A pattern exists across all living organisms where living things look similar, but not identical to their parents.

(Note: The focus should be on relating parents to offspring. In 2.LS3.1 students will look at organisms that are the same type, which is a bigger group than just parents and offspring.)

Scientific Ideas:

- We can describe the way that organisms look (their characteristics)
- Living organisms all come from other living organisms (e.g., plants come from seeds made by other plants, baby animals have parents)
- Some descriptions of living things are likely to be the same for both parents and offspring (e.g., the plant has thorns, the animal has a long nose).
- Sometimes the descriptions of living things will be different for parents and offspring (e.g., the parent has dark- colored leaves, but the leaves in the offspring look yellow, the parent's fur is mainly white with a few brown spots and the offspring's fur has many more brown spots).

Common Student Ideas:

- People look very different from their parents, but animals look almost the same.
- Plants do not have parents.
- …

Revised (2025 Implementation): K.LS3.1

K.LS3.1 – Collect and analyze observational data to show that young living things are like, but not exactly like, their parents.

3-5 Standards

By the end of grade 5. Many characteristics of organisms are inherited from their parents. Other characteristics result from individuals' interactions with the environment, which can range from diet to learning. Many characteristics involve both inheritance and environment. – NRC, 2012

Progression Across Grade Bands

In earlier grades, students learned to describe organisms' visible characteristics and observed that offspring look like their parents, but not exactly like their parents. Observing this pattern establishes that there is a way to explain the similarities between parent and offspring.

Students have observed similarities and differences between organisms and their parents. Students should learn that some differences may be a result of the interactions an organism has with its environment. The idea that differences may be caused by the environment or events in an organism's life is important because these differences will not follow patterns of inheritance. For example, plants that grow up in a nutrient- poor environment may not grow to as tall as their parents, and leaves may look yellow instead of green.

There are some behaviors in organisms that can be explained by inheritance, but organisms learn many behaviors when they interact with their surroundings. Some characteristics develop because of a combination of inheritance and environment.

Students will not learn about cells until middle school and will not address deoxyribonucleic acid (DNA) until high school. After students learn these concepts, they will be prepared to learn about mechanisms of inheritance and the influence of genes on characteristics at different scales.

Current (2018 Implementation): 5.LS3.1

5.LS3.1 – Distinguish between inherited characteristics and those characteristics that result from a direct interaction with the environment. Apply this concept by giving examples of characteristics of living organisms that are influenced by both inheritance and environment.

Big Ideas:

Characteristics in offspring can look different from their parents because of the effects of the environment and can look similar to their parents because of the idea of inheritance.

Scientific Ideas:

- Organisms have features that we can describe.
- All living things come from earlier living things – offspring have parents.

- Organisms will look similar to their parents because some of their features are inherited from their parents.
- Organisms interact with their environment (e.g., moving through the environment, obtaining materials from the environment).
- The appearance of an organism can change depending on how well its needs are met.
- Some changes to the appearance of an organism are temporary, but other changes to the appearance of an organism will last for the organism's lifetime.

Common Student Ideas:

- All changes to the appearance of an organism are permanent.
- The environment can only change the appearance of an organism when it harms or damages the organism (e.g., scars or lack of nutrients).
- …

Revised (2025 Implementation): 5.LS3.1

5.LS3.1 – Distinguish between inherited characteristics and those characteristics that result from a direct interaction with the environment. Apply this concept by giving examples of characteristics of living organisms that are influenced by both inheritance and the environment.

6-8 Standards

By the end of grade 8. Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of a specific protein, which in turn affects the traits of the individual (e.g., human skin color results from the actions of proteins that control the production of the pigment melanin). Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.

Sexual reproduction provides for transmission of genetic information to offspring through egg and sperm cells. These cells, which contain only one chromosome of each parent's chromosome pair, unite to form a new individual (offspring). Thus, offspring possess one instance of each parent's chromosome pair (forming a new chromosome pair). Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited or (more rarely) from mutations. (Boundary: The stress here is on the impact of gene transmission in reproduction, not the mechanism.) – NRC, 2012

Progression Across Grade Bands

In earlier grades, students learn that there are both similarities and differences when we compare offspring and their parents. Sometimes organisms look or behave differently from their parents because of influences from the environment.

The biggest piece of content that appears in middle school life sciences is cell theory – all living things are made of cells. Middle school standards about gametes, genes, and chromosomes introduce the basic components needed to understand how genetic information from parents is passed on to their offspring during sexual reproduction and new ways to account for differences.

Prior to middle school, students could only account for differences in the characteristics of parents and offspring that were caused by something in the environment. For example, plants grown without direct sunlight nutrients may be taller than their parents, or organisms may have unique scars or injuries. In middle school, students learn about genes which can also explain some differences between offspring and parents. A very small number of differences may be caused by mutations - changes to an organism's genes. Most differences arise because an offspring is a unique combination of alleles, half of which come from each parent.

Students must learn several ideas to articulate an explanation for the mechanism of inheritance. An organism's cells contain chromosomes that include many genes. Each gene produces a protein, and these proteins control the activities of cells and, in turn, organisms. Changes to an organism's genes can influence an organism's ability to produce a protein and this can cause differences in the characteristics between parent and offspring.

Although pedigrees are a way to identify dominant and recessive alleles, students should learn that dominant and recessive genes relate to the effect of the proteins in an organism. For example, the albinism trait occurs when organisms are unable to produce melanin. The trait is recessive because an organism's cells can produce melanin even if the cells only have one allele producing the melanin. Dominant phenotypes occur when only one allele produces enough of a given protein to cause the phenotype.

High school standards introduce the way that nucleic acids make up the structure of DNA. This information provides all of the necessary background for students to understand the way that DNA transfer and expression leads to organisms that look very much like their parents.

Current (2018 Implementation): 7.LS3.3

7.LS3.3 – Predict the probability of individual dominant and recessive alleles to be transmitted from each parent to offspring during sexual reproduction and represent the phenotypic and genotypic patterns using ratios.

Big Idea(s):

During sexual reproduction, parents pass on their genetic information to their offspring and this gene transfer explains the similarities and differences in the appearance of parents and offspring.

Scientific Ideas:

- Proteins carry out the reactions/control the appearance and functions of an organism. Or proteins determine the traits of an organism.
- Every gene encodes (is instructions for) the production of a single protein.
- Genes can be activated and deactivated, which means that they may/may not always lead to the production of their encoded protein.
- Genes can have variants that are called alleles.
- An allele is a variation of the gene that encodes for one version of a protein.
- Not all versions of a protein act the same way in the body.
- A dominant allele is a variation where the protein produced has an effect in on the body (e.g., melanin protein causes skin pigmentation).
- A recessive allele is a variant where the protein produced does not have a noticeable effect in the body (e.g., the melanin gene produces a protein that is an altered form of the melanin protein that does not cause skin pigmentation).
- In sexual reproduction, each parent contributes an allele for every gene.

- Egg and sperm cells that are made by parents contain half of the DNA of a normal cell.
- When an egg and sperm cell combine there is a complete set of DNA for a new organism.
- For nearly every trait, a person has two alleles in every cell of their body – one allele that came from their female parent and the other from their male parent.
- It is possible for both parents to have matching alleles in which case the offspring will receive a predictable combination of alleles.
- The alleles that are described as “dominant” will cover up recessive alleles, so it is not immediately obvious when a person.
- A person’s phenotype is the result of the combination of alleles/proteins encoded in their genes.

Common Student Ideas:

- An allele is a trait.
- An allele is a gene.
- …

Revised (2025 Implementation): 7.LS3.1

7.LS3.1 – Evaluate and communicate information that chromosomes contain many distinct genes which code for the production of proteins, impacting the traits of an individual.

9-12 Standards

In all organisms, the genetic instructions for forming species' characteristics are carried in the chromosomes. Each chromosome consists of a single, very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet- known function. – NRC, 2012

Progression Across Grade Bands

Inheritance describes an observable pattern that organisms possess characteristics that are a blend of their parents' characteristics. Parent generations produce molecules of DNA that are passed to their offspring. The similarities between the genomes of parents and their offspring explain the similarities in the characteristics between parent generations and their offspring since an organism's characteristics arise from the expression of its genome.

The progression about of traits begins with students learning to think about an organism as a collection of features, such as leaf shape and arrangement, texture of bark, or fur color. By comparing parents to offspring, students uncover that organisms look more like their parents and less like unrelated organisms, even organisms of the same type. Students also learn that organisms don' not look exactly like either parent and that interactions with the environment can explain some differences between parent and offspring. By the end of the intermediate grades, students should be able to describe the inheritance as a pattern.

Students should reach high school with an understanding that inheritance explains why there are similarities between parents and their offspring. In middle school, students learn that chromosomes contain genes from both parents and that the transfer of these genes from parent to offspring is the mechanism for inheritance. Students have not learned specifically about DNA, nor that genes are also organized. It is important for students to understand that all cells contain all genes, and that the expression of different genes explains the variety of cells that arise as the cells in multicellular organisms divide and differentiate.

In middle school, students learn that an organism's appearance and behaviors have a basis in their genes. This development makes it possible for students to begin to understand a mechanism for inheritance. The gene – as a segment of a chromosome – provides a physical connection between parent and offspring that can explain why organisms resemble their parents.

In high school, the mechanism for inheritance is completed. There is overlap between some of these ideas and ideas about gene structure. Some of the biology ideas from LS1.A also help students understand ideas about gene regulation. The standards in this component idea support an understanding of how every cell in a multicellular organism comes to possess a full copy of its genome.

Revised (2025 Implementation): Bio1.LS3.1, Bio1.LS3.2

Bio1.LS3.1 – Engage in an argument from evidence that the process of cellular division (mitosis) creates diploid daughter cells that are genetically identical to the diploid parent cells.

Big Idea(s):

Proliferation of single- celled organisms and the growth and proliferation of multicellular organisms depends on the ability of one cell to reproduce and distribute its entire genome to future cell generations.

Scientific Ideas:

- Organisms are a collection of physical and behavioral characteristics. These characteristics are determined by the expression genes in the organism's genome.
- The cell is the basic unit of life. Some organisms consist of only a single cell, while other organisms consist of many united cells.
- The preservation of an organism's genome through successive divisions is essential to the existence of the variety of species of living organisms. Without the ability to preserve its genome, cell lineages would not exist.
- In sexually reproducing organisms, the larger organism develops through successive divisions from a single cell.
- Every cell in the larger organism contains a complete copy of the organism's genome; an therefore, organisms must possess mechanisms to for each cell to receive it's copy of the larger genome.
- A cell acquires its copy of the genome as part of the reproductive process.
- In organisms that reproduce sexually, the development of the larger organisms arises from a single fertilized embryo. This embryo consists of two copies of each gene and in successive divisions of the embryo, every cell receives a copy of the duplicated genome.
- The formation of genetically identical cells depends on two essential features – the replication of the organism's DNA and the division of the cell into two new cells that each receive one complete set of the original cell's DNA.
- The cells that result from cell division have two copies of every gene – the same copies as the original cell.

- Cells produce a variety of structures to support the distribution of the replicated DNA to daughter cells. Cells produce various structures to support the distribution of the replicated DNA to daughter cells.

Common Student Ideas:

- Mitosis only occurs in single- celled organisms.
- All single- celled organisms go through mitosis.

Bio1.LS3.2 – Engage in an argument from evidence that the process of meiosis exists to create genetic variation in a population from the creation of new combinations of genetic material in each of the haploid gametes.

Big Idea(s):

Individuals look similar to, but not exactly like their parents. Individuals look like their parents. Meiosis provides a mechanism to explain why an individual does not look exactly like either parent, but rather a blend of their parents.

(Note: Emphasis should be on ideas of the benefits of a duplicate genome, with less emphasis on the individual steps of meiosis that create specialized reproductive cells.)

Scientific Ideas:

- It is advantageous to have duplicate copies of all genes. Duplicate copies increase the likelihood that beneficial mutations can arise and can provide a mechanism to mask harmful mutations. These competitive advantages have facilitated the survival and proliferation of organisms that utilize sexual reproduction.
- Organisms are a collection of traits and there is a pattern where organisms share many characteristics with their parents. Organisms are a collection of traits, and organisms share many characteristics with their parents.
- Chromosomes are a physical structure that passes from parent to offspring. Each chromosome is a single strand of DNA. One every chromosome there are many genes.
- Every gene on a chromosome has the potential to create a protein. The interactions among these proteins and other biomolecules are responsible for an organism's characteristics.
- Some aspects of an organism's appearance and behavior are determined by that organism's interactions with its surroundings.
- Individuals possess two copies of nearly every gene. Both genes have the potential to be expressed, and the organism's characteristics are determined by the combined expression of both copies.
- There are some sex-linked genes where individuals may have only one copy of a particular gene.

- The duplication of the organism's genome occurs because individuals receive one copy of each gene from each parent.
- Organisms that reproduce sexually produce specialized reproductive cells (pollen, spores, sperm, eggs). Each reproductive cell contains only one copy of each gene in the organism's genome. The union of two reproductive cells results in aan offspring with a unique genome consisting of one copy of each gene from each parent.
- Reproductive cells are a type of cell and like all other types of cells, they arise from the existing cells.
- The formation of reproductive cells is a must be a unique process because it creates cells with only one copy of each gene from a cell that originally possesses two copies of each gene.
- Some reproductive cells can remain viable even under conditions where the larger organism may not survive.

Common Student Ideas:

- Organisms only have one copy of each gene.
- Pollen, spores, eggs, and sperm are not cells.

LS3.B: Variation of Traits

Guiding Question:

Why do individuals of the same species vary in how they look, function, and behave?

The Biggest Ideas

PURPOSE

The purpose of this component idea is for students to be able to explain why organisms look different, even if they are the same type and why there are so many ways that they can vary.

CENTRAL IDEA(S)

Organisms can be put into groups with similar features. Within these groups, no individuals will be identical. Variation from parent to offspring happens because the offspring receives half of its genetic information from each parent. New variations can emerge in a population through the expression of recessive alleles or in rare cases through mutations that can be inherited.

GENERAL PROGRESSION

Grade Band	Scale	Observation
K-2	Organisms of the same kind	Variation exists in the differences in the appearances of organisms.
3-5	Traits in organisms of the same kind.	Variation exists in the different versions of the same trait.
6-8	Genes in an individual	Variation arises because offspring inherit two copies of each gene and rarely, mutations might create alleles.
9-12	DNA	Variation arises because of differences in the regulation and expression of genes.

This component idea begins with students developing an idea that there are different types of living things and observing that even if two living things are the same type, they do not look identical. In late elementary school, students learn that some variation emerges because offspring have characteristics that are a blend of their parents. In middle school, students learn about genes. As students learn about gene expression through proteins, they can explain variation that emerges when non-dominant phenotypes appear in a population and how new variants can emerge through changes to genes.

K-2 Standards

By the end of grade 2. Individuals of the same kind of plant or animal are recognizable as similar but can also vary in many ways. – NRC, 2012

Progression Across Grade Bands:

There are two broad ideas for this grade band – there are types of organisms and within these types, there are ways that individual organisms look different. For example, if we look at a group of zinnia flowers, we can find some things that look the same in every plant. If we use our list of features of zinnias, we can also look at other plants and determine that they are not zinnias. However, even within a group of zinnia flowers, we may find many different colors of blooms. *(Note: Systems of classification are beyond the intent of this component idea.)*

The objectives for this grade band require two types of observations. The first set of observations should help students identify that there are "types" of organisms. The second set of observations should lead students to see that even within the same type of organism, there are differences. Even though the flowers look different (variation) there are enough similarities that we can tell that all the flowers are the same type.

The differences within one type of organism become the focus of the remainder of this component idea, but it is important to establish that there are "types" of organisms first. Later in the elementary grade band students will formally talk about inheritance to see that offspring have some features that are like one parent and other features that are more like the other parent. By middle school, students can apply cell theory to explain how variation happens when gametes from one parent combine with gametes from the other parent.

Current (2018 Implementation): 2.LS3.1

2.LS3.1 – Use evidence to explain that living things have physical traits inherited from parents and that variations in these traits exist in groups of similar organisms.

Big Ideas:

In a group of the same type (species) of organism, there will still be differences between individuals. *(Note: The focus is on a group of organisms that are the same type, but not necessarily related, and on differences that are not a result of the environment.)*

Scientific Ideas:

- Scientists classify groups of living organisms into different types based on similarities among members of the group.
- Organisms that are the same type will have many similarities.

- In a large group of organisms that are the same type there will be variations between individuals. *(Note: Variations refers to differences that are genetic.)*
- Scientists record descriptions of the variations in a group of organisms to identify patterns. (e.g., Most of the clover plants have 3 three leaves, but occasionally a clover will have 4 leaves.)
- Not all organisms that are the same type have the same parent.

Common Student Ideas:

- There are no differences between young organisms of the same type because they generally look the same.

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Offspring acquire a mix of traits from their biological parents. Different organisms vary in how they look and function because they have different inherited information. In each kind of organism, there is variation in the traits themselves, and different kinds of organisms may have different versions of the trait. The environment also affects the traits that an organism develops—differences in where they grow or in the food they consume may cause organisms that are related to end up looking or behaving differently. – NRC, 2012

Progression Across Grade Bands:

This progression begins with students identifying that living things can be placed into groups and that within these groups there are some features that look different between individuals even though they are the same type. The purpose of this progression attempts is to explain why individuals of the same type look different and explain how these differences arise.

Students can begin to understand that one reason that organisms look different is because they inherit features from both parents. An organism does not look identical to either parent, instead, they have some characteristics that resemble one parent and others that resemble the other parent. In later grades, students will also learn to explain why some features may not appear to resemble either parent. Siblings also look different because they inherit a different blend of their parents' features.

Organisms of the same type can end up looking very different from each other because there is variation in nearly every trait and there are many traits. Individuals look different because they each have a unique mix of traits they inherit from their parents and most individuals do not have the same parents.

There are also characteristics, such as producing flowers, which exist in different types of organisms. Students should develop an appreciation that variation within and across species results in an enormous amount of variation across living things – there is an endless variety of flower types, sizes, smells, colors, arrangements, etc. In later grades, students will learn how new variations can emerge.

Current (2018 Implementation): 5.LS3.2

5.LS3.2 – Provide evidence and analyze data that plants and animals have traits inherited from parents and that variations of these traits exist in a group of similar organisms.

<u>Big Ideas:</u>

The way an organism appears and functions is a result of inherited information that is passed from parent to offspring.

Scientific Ideas:

- Organisms have many different describable characteristics.
- Characteristics are passed from one generation to the next.
- Every different type of organism has some characteristics that are found in the majority of the organisms in that type.
- There are some characteristics that are less common in the group.
- Every individual has many traits – some traits are visible, but other traits control parts of the organisms we cannot see.
- Individuals are unique and different because they each have a unique blend of traits.
- Organisms of the same type can end up looking very different from each other because there are so many characteristics and therefore opportunities to be unique.
- The environment can have effects that cause organisms to look different.

Common Student Ideas:

- Variation refers to different traits.
- …

Revised (2025 Implementation): 5.LS3.2

5.LS3.2 – Provide evidence and analyze data that plants and animals have traits inherited from parents and that variations of these traits exist in a group of similar organisms.

6-8 Standards

By the end of grade 8. In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.

In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. – NRC, 2012

Progression Across Grade Bands:

This progression begins with students learning to arrange organisms into groups based on shared characteristics and to describe these characteristics. Students learn that there can be variations of a characteristic even within a group of organisms. Students learn that one source of variation is that organisms inherit a blend of characteristics from each parent, and this means they will not be identical to either parent or their siblings.

In middle school, students learn about the role of genes in inheritance and how proteins encoded by these genes influence an individual's characteristics. This allows students to consider a mechanism to explain how organisms become a blend of their parent's characteristics. Variation from parent to offspring occurs because the offspring receives genes from both parents and therefore the offspring's genome (complete set of traits) will not be identical to either parent. The parents may each contribute matching alleles or may contribute different alleles.

Genes provide a way to explain how new variations can emerge. Sometimes a "new variation" is not actually new but has been hidden in a population – for example, a pea plant that produces yellow peas appearing among a group of plants that mainly produce green peas. Alleles for some traits may exist in a population, but these alleles are masked by other alleles. The effects of the masked (recessive) alleles and their existence are concealed by the effects of dominant alleles. Students should be able to explain that parents may contribute a set of alleles and the blend of these alleles may not resemble either parent. Typical examples include offspring with a set of recessive alleles from parents with a dominant phenotype.

It is also possible that changes to genes can create alleles that are completely new. Mutations to in genes can create new variations for a characteristic. Mutations are rare and many factors make it unlikely that mutations will persist in a population.

Current (2018 Implementation): 7.LS3.1, 7.LS3.2

7.LS3.1 – Hypothesize that the impact of structural changes to genes (i.e., mutations) located on chromosomes may result in harmful, beneficial, or neutral effects to the structure and function of the organism.

Big Idea(s):

Mutations are a source of new variation in a population.

Scientific Ideas:

- Chromosomes are found in all cells and contain many genes.
- Each gene contains information the body uses to make a specific protein.
- Each protein has a specific function in the cell/body and must be constructed properly in order to function properly.
- Chromosomes can mutate/change and this effect affects on the genes located on that chromosome.
- Some changes to chromosomes do not cause changes to the protein produced. *(Boundary: Students are not expected to understand that chromosomes are made of nucleic acids or protein synthesis.)*
- If a change occurs in a body cell, it can affect the individual but is not likely to affect their offspring.
- Changes to chromosomes in reproductive cells (egg and sperm) will be passed to offspring and can continue to remain in a population.
- Changes in reproductive cells create new variation in a population.
- Mutations in reproductive cells are not common.

Common Student Ideas:

- Variation refers to the very different types of organisms that are found on Earth.
- All mutations will have visible effects.
- …

7.LS3.2 – Distinguish between mitosis and meiosis and compare the resulting daughter cells.

Big Idea(s):

Meiosis is a special type of cell division that is only used to produce reproductive cells.

Scientific Ideas:

- There are different types of cells in a multicellular organism.
- All cells contain two alleles (copies) for each gene because they have two of each chromosome.

- Non-reproductive cells create new identical cells that are a copy of the parent generation when they divide.
- Reproductive cells are a special type of cell that are only found in organisms that reproduce sexually.
- Reproductive cells are made by sexually reproducing organisms and contain half of the number of chromosomes – only one copy of each gene.
- Sexual reproduction involves the combination of two cells to create a new cell.
- Each of the two cells involved in sexual reproduction has half the amount of DNA as a typical cell and when they combine the resulting cell contains the typical amount of DNA.
- Because offspring inherit half of their genes from each parent, the genes' offspring will be different from the parents.
- The difference between offspring genes and parent genes keeps variation in a group of the same type of organisms.
- Without the mechanism of meiosis, organisms would all look identical to one of their parents.

<u>Common Student Ideas:</u>

- All cells in the body have the potential to go through meiosis.
- Meiosis is another version of the cell cycle.
- At some point, all cells eventually go through meiosis.
- All variation in a population is a result of mutations.
- Variation refers to the very different types of organisms that are found on Earth.
- …

Revised (2025 Implementation): 7.LS3.2, 7.LS3.3

7.LS3.2 – Construct an explanation to describe how the impact of changes to genes (i.e., mutations) located on chromosomes may result in harmful, beneficial, or neutral effects to the structure and function of the organism.

7.LS3.3 – Predict the probability of individual dominant and recessive alleles to be transmitted from each parent to offspring during sexual reproduction and represent the phenotypic and genotypic patterns using ratios.

9-12 Standards

In all organisms, the genetic instructions for forming species' characteristics are carried in the chromosomes. Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet- known function. – NRC, 2012

Progression Across Grade Bands

Students begin this progression by developing an understanding that it is possible to group or categorize living things based on shared characteristics. Within these groups of like things, students should also have described how the organisms look different. Variation refers to the small differences that exist within a group of similar things.

In the intermediate grades, students begin to discuss the idea of inheritance (LS3.A). Students should identify that variation exists even between parents and offspring. Inheritance also explains why individuals with the same parents look more similar than individuals with different parents. Students may again look within groups of like individuals and begin to place the differences into groups. For example, students may create two groups of trees – those that produce acorns and those that do not produce acorns. Within the group of trees that all produce acorns, there are further differences in the shapes of the individual acorns. Students should understand that the shape of the acorn is a trait that the tree inherited from its parents and that some additional differences may come from environmental factors, – such as insects that create holes in the acorns.

Genes – segments of chromosomes –- provide the physical mechanism that transfers information from parent to offspring. In middle school, students learn to explain that variation between parent and offspring arises because each offspring possesses a duplicate set of all genes. The combination of alleles in offspring may be different from either parent and explains variation between parents and offspring. Students don' not learn any details about the structure or decoding of DNA until high school.

Some of the concepts for this component idea overlap with standards from component idea LS1.A. The two big takeaways for high school should be the ability to explain how gene expression contributes to the observable variations in a population and to explain how variations of a trait can arise in a population due to changes in genes.

Revised (2025 Implementation): Bio1.LS3.3, Bio1.LS3.4

Bio1.LS3.3 – Ask questions to clarify that variation of traits arises from differences in genes (alleles) and how cells regulate gene expression.

Big Idea(s):

Variation in the appearance and behaviors of individuals is due, in part, to the existence of multiple possible alleles for each gene as well as mechanisms that determine when a particular gene may be expressed.

Scientific Ideas:

Variation occurs at a variety of scales:

- Variation in populations
  - The gene pool of a population consists of the genes of all members in the population.
  - Every organism possesses a unique collection of genes which encode the range of proteins that organism produces. Every organism has a unique collection of genes that encodes the range of proteins it produces.
  - For a given characteristic, each member of the population will have two copies of that gene with the potential to have two different alleles.
  - There can be more than two possible alleles for each different gene.
  - Offspring receive one variation of each gene from each parent when gametes combine during fertilization. Offspring can possess allele combinations that are different than their parents.
- Variation in individuals
  - A gene is a section of DNA (a type of nucleic acid) that can be tightly condensed to form chromosomes.
  - An organism has two copies of nearly all of the genes in its genome.
  - The copies of each gene are not necessarily the same – organisms frequently have two different alleles for the same gene.
- Variation in gene expression
  - The process that produces a protein begins with the transcription of the gene.
  - Each gene has a coding portion that is transcribed during protein synthesis as well as regulatory proteins.
  - Proteins bind to regulatory portions of genes and prevent the transcription of that gene.
  - The proteins that bind to regulatory portions of genes can unbind in the presence of certain other molecules.

Common Student Ideas:

- Genes are always “on.”.

- The only way for phenotypic differences to arise is to have different allele combinations.
- There are large genetic differences between individuals since there are so many different alleles.

Bio1.LS3.4 – Construct an explanation based on evidence that genetic variations may result from (a) new genetic combinations via the processes of crossing over and random segregation of chromosomes during meiosis, (b) mutations that occur during replication, and/or (c) mutations caused by environmental factors. Evidence should include that mutations that occur in gametes can be passed to offspring.

Big Idea(s):

There are multiple factors that contribute to variation observed in a population. These factors include the sorting of genes that occurs during the development of reproductive cells, as well as changes to the physical DNA molecule.

Scientific Ideas:

- Sexual reproduction involves the production and fusion of haploid reproductive cells (gametes) from diploid cells (gametophytes).
- There are a variety of types of haploid reproductive cells found in different types of organisms, such as pollen, spores, eggs, and sperm.
- Crossing over and random segregation occur during the formation of gametes and can produce gametes with unique allele combinations.
    - Random segregation leads to gametes with new variations in the combinations of alleles found on different chromosomes.
    - Crossing over leads to new variations in the combinations of alleles within a single chromosome.
- New alleles for a gene occur because of changes to the DNA.
    - Organisms produce proteins through a series of chemical reactions that begin with DNA molecules.
    - A DNA molecule is a long chain of complimentarily paired nucleotides. The order of the nucleotides determines the protein that is produced during protein synthesis. The nucleotide order determines the protein produced during protein synthesis.
    - Mutations are changes to the order of nucleotides that can therefore change the protein encoded by a gene or prevent the expression of the entire gene.
    - Not all changes to the order of nucleotides result in new alleles.
- Not all changes to alleles can pass from parent to offspring.
    - Organisms obtain their unique genotype when gametes fuse during fertilization.
    - New alleles will might arise during gamete formation or very early in embryogenesis.

    - Mutations that occur in a parent’s body cells are not likely to change the DNA of the parent’s gametes.

Common Student Ideas:

- Gametes contain all of the parent’s alleles. Gametes contain all the parent’s alleles.
- Random segregation and crossing over produce new alleles.
- Mutations will always result in new phenotypes.

LS4.A: Evidence of Common Ancestry and Diversity

Guiding Question:

What evidence shows that different species are related?

The Biggest Ideas

PURPOSE

Earth's history and present- day includes many different types of living things (diversity) and there are characteristics that are common across this diversity (common features). Common ancestry explains these observations about living things.

CENTRAL IDEA(S)

Over time, Earth's species have changed: some have become extinct, and new ones have emerged. Evidence, like fossils, shows this shift. New species emerge from other species because of opportunity and environmental pressures. This process explains Earth's many different types of living things and the common features among organisms.

GENERAL PROGRESSION

Grade Band	Observation
K-2	Things that live on Earth today have similar body shapes and features as extinct organisms.
3-5	Common features exist in the fossilized parts of plants, animals, and microbes relative to other fossils and organisms found on Earth today.
6-8	Common ancestry provides a scientific explanation for the patterns in common features among organisms.
9-12	Analysis of common features in embryonic stages and genomes supports explanations of common ancestry and infer lines of descent.

This component idea first explores the diversity and common features of living things by looking at the types of animals and plants that were once found on Earth but cannot be found living anywhere today. Later, students learn to make comparisons between fossils and organisms alive today. When students understand chemical reactions, they are prepared to consider how fossils form, why fossilization is such a rare occurrence, and how these factors influence the fossil record.

K-2 Standards

By the end of grade 2. Some kinds of plants and animals that once lived on Earth (e.g., dinosaurs) are no longer found anywhere, although others now living (e.g., lizards) resemble them in some ways. – NRC, 2012

Progression Across Grade Bands:

Young students are often fascinated by dinosaurs and other organisms that are no longer found living on Earth. They can use scientific illustrations to compare features of living things and extinct things. For example, they might notice that some dinosaurs, like some animals today, had four legs, wings, claws, etc. The goal is to show that while some organisms that once lived on Earth are no longer found anywhere (diversity) these extinct organisms have similarities to existing ones (common features). Standards in this component idea connect with others exploring grouping and patterns such as standards in component ideas LS1.A, LS3.A, and PS1.A.

Students are likely to think about fossils whenever they discussion organisms like dinosaurs that are no longer found on Earth. However, fossils are addressed in later grades. By late elementary, students grasp that organisms have both internal and external structures that can be fossilized, preserving details about organisms and their habitat. In middle school, they learn about the chemical processes involved in fossilization and why it 'is rare. This knowledge helps them understand how the fossil record supports explanations for life's diversity and similarities among living things, as well as limitations of the fossil record.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Fossils provide evidence about the types of organisms (both visible and microscopic) that lived long ago and also about the nature of their environments. Fossils can be compared with one another and to living organisms according to their similarities and differences. – NRC, 2012

Progression Across Grade Bands:

In early grades, students learned that some organisms that existed on Earth in the past are now extinct. They used artists' renderings to compare the external features of extinct and extant organisms. They learned that there were many different types of organisms that once lived on Earth, which shared many similarities with organisms that are still found on Earth.

Students may not realize that the depictions of dinosaurs they have seen are created by artists or on computers based on fossils. As they begin to explore the internal structures of organisms (LS1.A), they are more likely to understand how scientists can create such renderings from collections or fragments of larger fossils. For example, when students how bones and muscles work together (as a system) to coordinate movement, they are prepared to understand how scientists can estimate what the muscles and bodies of dinosaurs may have looked like based on fossilized skeletons. Fossils not only offer clues about the behaviors and habitats of ancient organisms but also about the environments they inhabited.

This component idea focuses on the diversity of living things and common features among those organisms. Applying an understanding of structure and function helps scientists understand why common features persist over time – such as the shape of teeth or joints.

Students often associate fossils with big reptiles and mammals. But as they broaden their understanding of living things to include the microscopic world in this grade band, they should also realize that even tiny things can also become fossils. Tiny fossils of pollen, seeds, teeth of other living things, and shells are plentiful and provide information about past environments.

With an understanding of chemical reactions in middle school, students will be prepared to consider how fossils form, why this process is rare, and how the collection of fossils preserved in layers of sediment across Earth provides are record of features persisting over time and the formation of past and present diversity of living things.

Current (2018 Implementation): 4.LS4.1, 5.LS4.1

4.LS4.1 – Obtain information about what a fossil is and ways a fossil can provide information about the past.

<u>Big Ideas:</u>

Fossils provide information about animals that once lived and about the way that Earth used to look.

Scientific Ideas:

- Fossils are found inside of other rocks, buried, or in places where the ground has been washed/broken away.
- Fossils come from things that used to live on Earth but are not the actual parts of the animals.
- Fossils tell us about the basic shape (morphology) of an organism.
- Groups of fossils can tell us about the lifestyle and life cycle of different types of organisms (e.g., that organisms traveled in groups, raised their young, built nests).
- Organisms also leave evidence including in their environment that scientists can use to hypothesize about the behavior of dinosaurs (e.g., footprints tell us about the walking patterns of dinosaurs, teeth, and digestive stones – gastroliths – provide information about diet).

Common Student Ideas:

- Only big things can become fossils.
- Fossils are animal bones that are left behind when an animal dies.
- We have or expect to find fossils for of all the different types of animals that once lived.
- Fossils can tell us exactly what an organism looked like.
- ...

5.LS4.1 – Analyze and interpret data from fossils to describe types of organisms and their environments that existed long ago. Compare similarities and differences of those to living organisms and their environments. Recognize that most kinds of animals (and plants) that once lived on Earth are now extinct.

Big Ideas:

Fossils provide information about animals that once lived and about the way that Earth used to look.

Scientific Ideas:

- Fossils tell us about the basic shape (morphology) of an organism.
- Scientists draw many conclusions about dinosaurs by comparing fossils to organisms that are still alive today (e.g., the size and strength of bones allows scientists to estimate the size of dinosaurs).
- Groups of fossils can tell us about the lifestyle and life cycle of different types of organisms (e.g., that organisms traveled in groups, raised their young, built nests).

- Organisms also leave evidence including in their environment that scientists can use to hypothesize about the behavior of dinosaurs (e.g., footprints tell us about the walking patterns of dinosaurs, teeth, and digestive stones – gastroliths – provide information about diet).
- The types of fossils found in an area allow us to understand the way that a place looked long ago (e.g., marine fossils throughout Tennessee tell us that this was once an area covered by water).

Common Student Ideas:

- There were different types of animals that existed long ago on Earth, but the types of plants were the same.
- …

Revised (2025 Implementation): 4.LS4.1

4.LS4.1 – Obtain, evaluate, and communicate information about what a fossil is and ways a fossil can provide information about the past, such as a) the nature of environments and b) animals that existed long ago but no longer exist.

6-8 Standards

By the end of grade 8. Fossils are mineral replacements, preserved remains, or traces of organisms that lived in the past. Thousands of layers of sedimentary rock not only provide evidence of the history of Earth itself but also of changes in organisms whose fossil remains have been found in those layers. The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth. Because of the conditions necessary for their preservation, not all types of organisms that existed in the past have left fossils that can be retrieved. Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully formed anatomy.

– NRC, 2012

Progression Across Grade Bands:

Many different types of organisms have lived on Earth (diversity). Some of these are no longer found here, but we can use fossils to learn about them. There are characteristics (e.g., four legs, claws, teeth) that we see in both present- day and extinct organisms (common features). Students have observed such common features in artists' renderings (K-2) as well as fossils (3-5).

Common features exist across many different groups of organisms. This component idea examines the evidence for common ancestry as a scientific explanation for the cause of shared features within the diversity of life on Earth. In the middle grades physical science students learn about the different elements in the universe and how they rearrange during chemical reactions. This prepares students to understand that atoms rearrange to produce fossils and that the necessary conditions required for a fossil to form make fossils of some organisms so rare. When students understand that fossilization is rare and how the process occurs, they can understand the meaning of the fossil record and how it preserves a record of some of the organisms that once lived on Earth. This record supports explanations of how life changed over the course of Earth's history.

Current (2018 Implementation): 8.LS4.1, 8.LS4.2

8.LS4.1 – Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change in life forms throughout Earth's history.

Big Idea(s):

Scientists are able to reconstruct the history of life and location on Earth over time because of our understanding of the events and conditions needed to create fossils.

Scientific Ideas:

- Looking at a collection of fossils and the information they leave about the past allows scientists to reconstruct a history of how life has changed over time and events in Earth's history.
- Fossils form when the remains of living organisms are replaced by minerals, leaving behind an artifact that is no longer chemically the same as the original bone.
- Bones and tissues of organisms will usually not become fossils.
- The conditions needed for fossilization are rare.
    - Remains of deceased organisms must not decompose fully.
    - Sediment must cover the undisturbed remains.
    - Minerals must be present and accumulate over long periods of time.
- Because the conditions needed for fossils to form are so specific, most of the organisms that once lived are not present in the fossil record.
- Most fossils form in sedimentary rock.
- Sediment will accumulate on top of other layers of sediment and therefore the older layers of sediment are located under younger layers of sediment.
- Fossils located in layers of lower layers sedimentary rock are older than fossils in upper layers.
- The fossil record reconstructs the sequence of life on eEarth based on the principle that older fossils will be found under younger fossils.

Common Student Ideas:

- Fossils are the actual bones of organisms that once lived. (vs. mineral replacements.)
- …

8.LS4.2 – Construct an explanation addressing similarities and differences of in the anatomical structures and genetic information between extinct and extant organisms using evidence of common ancestry and patterns between taxa.

Big Idea(s):

Genetic evidence supports the relationships inferred by anatomical similarities between different organisms.

Scientific Ideas:

- Relationships can be inferred by looking at anatomical similarities between organisms.

- Changes to organisms occur over generations, not in a single generation.
- Fossils are rare and because of this, the fossil record will not show a smooth progression of changes across generations.
- Living organisms can and have been classified based on patterns in their anatomical structure.
- Organisms pass on genetic information to their offspring.
- Similarities in the genes of organisms deemed to be closely related based on anatomical similarities validate the idea that organisms can be classified based on anatomical similarities.
- The fossil record infers lines of descent based on anatomical similarities.

Common Student Ideas:

- Changes that create new species or differences between organisms happen quickly.
- The fossil record is a complete record of every organism that has lived on Earth.
- …

Revised (2025 Implementation): 8.LS4.1, 8.LS4.2

8.LS4.1 – Using evidence from the geologic timescale, analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change in life forms throughout Earth's history.

8.LS4.2 – Construct an explanation addressing similarities and differences of in the anatomical structures and genetic information between extinct and extant organisms using evidence of common ancestry and patterns between taxa.

9-12 Standards

Genetic information, like the fossil record, also provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.–evidence. – NRC, 2012

Progression Across Grade Bands

Earth has been inhabited and is presently inhabited by an incredible diversity of living things. While the term "diversity" may suggest "differences," there are a variety of common features among groups of organisms. Students have been observing common features among extinct and extant organisms since the earliest grades. In high school, students merge their understandings of cell division and cell differentiation to explain how organisms that may have very different adult forms can still possess similarities during embryonic development. For example, fish, human, and other vertebrata have a pharyngeal pouch in embryonic stages. Though this feature is common in embryonic stages, as the embryo develops, the pouches develop into gills in fishes and a variety of structures in the inner ear of humans. These changes make some similarities harder to recognize.

Students have discussed fossils in various ways since late elementary school. Students begin to explore the fossil record in middle school. Throughout the fossil record, we observe transitional fossils that link current organisms to ancestral forms. Evidence supporting the explanation of common ancestry and biological evolution extends to the molecular scale where we see common stages of DNA and translated amino acid sequences.

Revised (2025 Implementation): Bio1.LS4.1

Bio1.LS4.1 – Analyze and interpret scientific data that common ancestry and biological evolution are supported by multiple lines of empirical evidence (e.g. DNA sequences, amino acid sequences, anatomical structures, the fossil record, biogeography, or order of appearance of structures during embryological development).

<u>Big Idea(s):</u>

Common ancestry and biological evolution can explain the common features shared among various groups of organisms. Advancements in technology have provided lines of evidence and new representations of this evidence which continue to support existing explanations.

<u>Scientific Ideas:</u>

Common features:

- Organisms can be classified/grouped based on common features. (Note: The idea is to identify common features within a group, not to memorize specific features that are common within a group.)
- Common features may include internal and external parts, which may have different functions despite similar appearances in different organisms.
- Organisms share common features during embryonic stages. Ultimately, these shared embryonic features may develop into different structures as cells continue to differentiate into adult forms.

Common ancestry:

- Common ancestry is the scientific explanation for common features.
- A feature that is common among a group of originated in an earlier ancestor shared by the group. A common feature among a group originated in an earlier ancestor shared by the group.
- Fossilized remains of organisms that once lived include transitional fossils that possess intermediate forms that existed between an ancient ancestor of a more recent organism.
- The present and historical distribution of Earth's species supports common ancestry.
    - Organisms that have been geographically isolated together possess distinct features that are unique to organisms in that area. These features emerge after a place becomes isolated.
    - When a population becomes geographically divided and the separate populations remain isolated, the unique pressures in each environment can favor the selection of different features in each environment. Features shared between these population originated in a common ancestor before the populations were divided.
- Patterns in similarities in DNA/amino acid sequences support those groupings initially inferred based on common features. Patterns in similarities in DNA/amino acid sequences support those groupings first inferred based on common features.
    - Organisms grouped based on common features have a large number of genes in common. Organisms grouped based on common features have many genes in common.
    - Genes that are common in different species often have large numbers of conserved nucleotide sequences. Genes common in different species often have many conserved nucleotide sequences.

<u>Common Student Ideas:</u>

- More recent ancestors are more advanced than earlier ancestors.
- Organisms with a common ancestor will only differ by a single trait.

- When two organisms share a common ancestor, it means that one of the organisms is a more advanced version of the other organism.

LS4.B: Natural Selection

Guiding Question:

How does genetic variation among organisms affect survival and reproduction?

The Biggest Ideas:

PURPOSE
This strand examines why some traits become more common than others in a population of organisms.

CENTRAL IDEA(S):
Natural selection has several key components. There must be variation in a population. Variation refers to multiple forms of a single characteristic. The variation must create advantages in the survival and reproduction of some members of the population over other members. And it must be possible to pass the beneficial variation on to offspring. Under these conditions, some traits will become more common in a population over many generations.

GENERAL PROGRESSION

Grade Band	Development
K-2	No content
3-5	Within a species, some individuals have advantages regarding survival, finding a mate, and reproducing.
6-8	Inheritance of advantageous traits causes those traits to become more common in a species over time.
9-12	Natural selection requires the expression of genetic variation.

This progression begins by having students consider why some forms of a trait may provide advantages. By middle school, students are prepared to consider the cumulative effects of the advantages over generations that can cause some characteristics to become more common in a group of organisms.

K-2 Standards

By the end of grade 2. [Intentionally left blank] – NRC, 2012

Progression Across Grade Bands:

There is no K-2 content for this component idea. In these grades, LS1 standards explore the function of external structures of organisms. LS3 standards compare parents to offspring, or individuals to other members of their species. These LS1 and LS3 concepts provide background knowledge that help students understand the principle of natural selection in later grades.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing. - NRC, 2012

Progression Across Grade Bands:

A species is a group of organisms that can produce offspring. There can be multiple appearances for a single characteristic within a species. For example, there are many different variations and varieties of the sunflower species (*Helianthis annis*). Sunflowers can be short or very tall. They can have large flower heads or smaller flower heads. Some have bright yellow flowers and others have red, brown, or orange flowers. In later grades, students will learn how changes to genes can produce these different characteristics.

Species have unique needs and there are limited resources to meet these needs. Living things with similar needs may not survive if other organisms use the resources first. Sunflowers need plenty of sunlight and won't grow well in the shade of another plant. In the wild, sunflowers grow in places such as grass lands where they compete for sunlight with taller grasses. In these conditions, sunflowers that germinate quickly and grow taller are more likely to reach the sunlight before tall grasses cover them with shade.

Reproduction is an important part of natural selection. Characteristics that are an advantage only become more prevalent in the population if the organisms that possess the advantages are survive and pass the characteristics on to their offspring. Height might be an advantage for sunflowers if pollinators are more likely to visit tall sunflowers that stand above the grasses. This would make it more likely that these sunflowers produce seeds.

In later grades, students will explore the two fundamental ideas about natural selection – natural processes can lead to new variations of existing characteristics and when these characteristics can be inherited and provide an advantage to certain organisms, they tend to become more common in a population. Some variations of a characteristic can become less common when they cause organisms to fail to survive and reproduce because it means that there will not be offspring to inherit the variation.

At this point, the focus is on individuals not on populations, and students are not thinking about passing on the advantageous trait to their offspring. For these reasons, students are not expected to consider why a particular trait may be more common than another in a population until later grades. The term "natural selection" will not emerge until middle school when students are able to consider that the differences in the characteristics of individuals is caused by differences in their genes. In middle grades, students will also consider that artificial selection, like natural selection, will lead to some characteristics becoming more common in a population.

(Note: Component idea LS1.A addresses how plants and animals use external structures. The LS4.B progression is different because it is about how one variation of a characteristic is beneficial over another variation of the same characteristic.)

Current (2018 Implementation): 5.LS4.2

5.LS4.2 – Use evidence to construct an explanation for how variations in characteristics among individuals within the same species may provide advantages to these individuals in their survival and reproduction.

Big Ideas:

Sometimes the differences between individuals that are the same species are helpful and allow some individuals advantages over others.

Scientific Ideas:

- Organisms use their structures for specific purposes or a variety of purposes.
- Organisms have characteristics that can be observed and described.
- Every individual organism has characteristics that make it different from other organisms that are the same type.
- Generally, all individuals that are the same type have identical needs and have similar approaches to the way that they meet their needs.
- The life cycle of living organisms includes maturing and reproducing.
- Organisms can only survive in a certain range of conditions and when their needs are met.
- The differences between individuals may be helpful/harmful to the individuals.
- Differences may allow certain individuals to survive/thrive in conditions where other organisms may not survive (more/less sun, more less water, more/less heat, etc.)
- Differences may allow some organisms to reproduce more easily or increase the chance that offspring will survive through the earliest parts of development.

Common Student Ideas:

- All members of the same species are equally suited to survive in the same conditions.
- Advantages will always be visible changes to the appearance of an organism.
- …

Revised (2025 Implementation): 5.LS4.1

5.LS4.1 – Use evidence to construct an explanation for how variations in characteristics among individuals within the same species may provide advantages to these individuals in their survival and reproduction.

6-8 Standards

By the end of grade 8. Genetic variations among individuals in a population give some individuals an advantage in surviving and reproducing in their environment. This is known as natural selection. It leads to the predominance of certain traits in a population and the suppression of others. In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. – NRC, 2012

Progression Across Grade Bands:

Standards in earlier grades explore how differences among individuals of the same species can provide advantages to some individuals. These advantages can mean that some individuals are more likely to survive, to find a mate, and to reproduce.

In middle school, the earlier ideas about surviving, finding a mate, and reproducing progress by considering the effect of these factors over time. Students are learning that offspring inherit genes from their parents. If one generation passes an advantageous characteristic to it's offspring, then those offspring might also be more likely to survive, mate, and reproduce. From one generation to the next, the advantageous characteristic continues to become more common in the population. This is the development in middle school – heritable characteristics that provide an advantage will become more common in a population over time.

A beneficial characteristic in plants is seed dormancy. Plants have genes that control when a seed germinates based on cues from the environment. For example, systems of genes may require a prolonged period of cold temperatures before the seed will sprout. These genes can prevent seeds from germinating near the end of summer or fall when cold temperatures during the approaching winter could kill the young plant. When this characteristic emerged in early plants, those plants had an advantage in survival and reproduction. As time went on, future generations inherited the characteristic and those individuals experienced higher survival rates. This pattern of inheritance, survival, and reproduction compounded, and a greater proportion of future generations exhibited the characteristic. This characteristic has proven so successful that it has been preserved through many species of plants.

Humans may also derive benefits from characteristics that emerge in a natural setting. For example, genes that control seed germination in barley plants are useful to humans who harvest and process the grain by ensuring that barley does not germinate before it is harvested and processed. Lab researchers identify plants with characteristics that pass from parent to offspring and choose to select these individuals to breed. This selective process can artificially influence the proportion of organisms exhibiting the desired characteristic.

Students learn that genes on chromosomes are the physical matter that passes from parent to offspring which makes inheritance possible.

In high school, students will explore genetic variation and the idea that natural selection can act on genetic variation when the variation leads to differences in the performance of individuals. Students will address specific factors required to establish the effects of natural selection in high school.

Current (2018 Implementation): 8.LS4.3, 8.LS4.4, 8.LS4.5

8.LS4.3 – Analyze evidence from geology, paleontology, and comparative anatomy to support that specific phenotypes within a population can increase the probability of survival of that species and lead to adaptation.

<u>Big Idea(s):</u>

Natural selection will create changes to the appearances of organisms over time and some of the changes to living organisms are captured in the fossil record and correspond with changes to the environment that are also preserved in eEarth's geologic history.

<u>Scientific Ideas:</u>

- The eEarth has changed throughout its history, and we can find evidence of some of these changes in a region's geology.
- The appearance and habits of species have changed over time and some of these changes are captured in Earth's fossil record.
- Relatedness between organisms can be inferred by similarities in the appearance of organisms.
- As conditions on Earth have changed, variation in a species has favored some organisms over others.
- Since most organisms do not become fossils after their death, fossils are more likely to reflect the dominant phenotypes at the time the organism lived.

<u>Common Student Ideas:</u>

- Adaptation happens within an organism's lifetime or a few generations.
- …

8.LS4.4 – Develop a scientific explanation of how natural selection helps play a role in determining the survival of a species in a changing environment.

<u>Big Idea(s):</u>

Changes to DNA can introduce new alleles in a population. Environmental conditions may favor some alleles over other alleles and result in an increase or decrease in certain alleles over generations.

Scientific Ideas:

- Genes control the functions and appearance of organisms.
- A single gene can produce more than one version of the same protein, and these different versions may not all perform their intended function.
- Since there are different versions (alleles) of each gene/protein, it is possible for individual organisms of the same type to look and behave differently from each other.
- Differences in appearance and behavior may be beneficial to some individuals than others of the same species.
- All organisms of the same species have the same general needs for survival and will survive only under certain conditions.
- Individual organisms that survive and reproduce will pass their genes on to the next generation.
- Only alleles that get passed from parent to offspring can become more common in a population.
- Alleles can become rare in a species as members of a less advantageous allele die off or do not reproduce.
- Over generations, alleles that give individuals an advantage over other members of their species will become more common in a population.
- Common needs and limited resources create competition which is one source of pressure that may affect which members of a population survive.
- Changes to the environment may accelerate normal rates of change in a population by limiting resources, changing local conditions.

Common Student Ideas:

- Any change to the appearance of an individual is a new allele.
- Changes in populations occur over just a few generations.
- …

8.LS4.5 – Obtain, evaluate, and communicate information about the technologies that have changed the way humans use artificial selection to influence the inheritance of desired traits in other organisms.

Big Idea(s):

When humans deliberately breed organisms, they select alleles for a variety of reasons and some of these alleles may not be advantageous to the species in the wild.

Scientific Ideas:

- Genes control the functions and appearance of organisms.
- A single gene can produce more than one version of the same protein, and these different versions may not all perform their intended function.

- Since there are different versions (alleles) of each gene/protein, it is possible for individual organisms of the same type to look and behave differently from each other.
- Humans use and enjoy different plants and animals for a variety of reasons and may prefer certain characteristics.
- Humans can control the breeding of other organisms in a way that limits the transmission of some genes and promotes the transmission of other genes.
- As humans promote the transmission of certain genes, those genes may become more common in a population.
- Genes that humans promote may not be favorable in the wild, and organisms possessing those genes may not survive outside of human care.

Common Student Ideas:

- Humans can “design” new genes that are not already found in nature.
- …

Revised (2025 Implementation): 8.LS4.3, 8.LS4.5

8.LS4.3 – Construct an explanation based on evidence that explains how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing.

8.LS4.5 – Obtain, evaluate, and communicate information about the technologies that have changed the way humans use artificial selection to influence the inheritance of desired traits in other organisms.

9-12 Standards

Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population, and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced and thus are more common in the population. – NRC, 2012

Progression Across Grade Bands

Natural selection has been introduced in earlier grades. Standards have focused only on those characteristics that provide advantages with respect to survival, finding a mate, and producing offspring. Natural selection only occurs when the advantages can be inherited and when the affected individuals reach reproductive age and pass the traits on to their young.

Gene expression is a critical development in high school genetics. In middle school, students learn that an organism's collection of traits are is a result of the variety of genes in its genome. New traits can emerge in an organism when there are changes to the organism's genes (DNA). However, not all changes to DNA result in differences in an individual being more successful at surviving, finding a mate, or producing offspring. Some changes to DNA may have no effect, even at the level of a the protein associated with the gene. Other changes might have an effect on the protein associated by a particular gene, but if that gene is not expressed, these changes may not cause meaningful differences. Other changes might affect the protein associated by a particular gene, but if that gene is not expressed, these changes may not cause meaningful differences. Still, other mutations might affect portions of a gene responsible for regulating the expression of the gene, but have no effect on the structure or function of the protein itself.

There is a pattern in nature where heritable traits with positive outcomes become more common in a population. This occurs because in each generation, affected individuals are more likely to reproduce. Repeated over many generations, the composition of the population shifts so that a greater proportion of the population exhibits the advantageous characteristics.

Revised (2025 Implementation): Bio1.LS4.2

Bio1.LS4.2 – Apply concepts of statistics (i.e. probability) to support explanations that organisms in a population with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

<u>Big Idea(s):</u>

New variations of a trait arise through changes to genes that result in phenotypic changes. It is possible to support that the new variation of the trait is advantageous based on the increasing frequency of the variation in the population.

<u>Scientific Ideas:</u>

New variants for a trait can emerge from changes to DNA.

- Traits are a result of the interaction of proteins with other biomolecules.
- Each trait results from the interaction of one or more proteins in an organism.
- Organisms make a variety of different proteins through a chain of chemical reactions beginning with DNA in the cell's nucleus. These proteins control an organism's traits.
- An organism's DNA is divided into genes where each gene is the starting place for production of a single protein.
- Some portions of a gene encode the production of a protein, while other portions of a gene control the expression of a gene.
- Changes to an organism's DNA can result in changes to the proteins produced or the control over the production of the protein.
- Selective pressures act on variations that affect the performance of the individual.
- Species tend to have significant variation within a population and less variation across different populations.

Natural selection explains changes in heritable characteristics in a species over generations.

- There can be multiple variants of a trait among members of the same species.
- Certain variations of a trait may provide advantages in the survival, finding a mate, and reproduction for individuals of a species.
- If an individual dies before they reproduce, then their combination of genes does not get passed to future generations.
- Individuals that who are more likely to survive, find a mate, and reproduce are more likely to pass their genes on than other individuals.
- An advantageous variation becomes more common in a population due to the cumulative effects of the advantage from one generation to the next.
- Natural selection only affects traits where one variant that provides an advantage to some members of a species.

Mathematical models can support claims that a particular trait is increasing in a population.

- Added together, the dominant and recessive alleles will account for all the alleles in a population.
- At equilibrium, the proportions of each variant remain relatively stable across generations.
- When environmental conditions are stable the proportion of alleles in the population can reach equilibrium.

- New alleles (from new members in the population, new mutations, etc.) cause a population to push a trait out of equilibrium.
- A trait will leave the equilibrium state when a characteristic provides an advantage in survival, finding a mate, and reproducing.
- Artificial selection can cause a population to fall out of equilibrium.
- Selective pressures acting on a population will return a system to equilibrium.

Common Student Ideas:

- After enough time, natural selection will remove all recessive alleles from a population.
- After enough time, only dominant alleles will occur in a population.
- Dominant alleles will always be more common in a population.
- Genetic variation will decrease over time as dominant alleles push out recessive alleles in the population.
- There can only be one recessive allele and one dominant allele for a particular gene.
- Changes to allele frequencies always happen quickly. (Note: Typically, only happens due to external pressure, such as isolating a portion of a population).
- Changes to allele frequencies only happen slowly. (Typical, but external or artificial pressures can accelerate changes in frequency.)
- In an equilibrium state, the different variations of a trait occur in equal proportions.

LS4.C: Adaptation

Guiding Question:

How does the environment influence populations of organisms over multiple generations?

The Biggest Ideas:

PURPOSE
This strand examines how adaptation leads to a population that is better suited to its environment.

CENTRAL IDEA(S):
When an environment changes, characteristics that may not have been favorable under prior conditions may become advantageous. Over generations, natural selection causes favored characteristics may become more common in the population. It is possible for new species to arise from existing species when there are significant changes to the environment that separate parts of existing populations.

GENERAL PROGRESSION

Grade Band	Development
K-2	There are places where conditions are too extreme for living things to survive.
3-5	Changes to the environment can affect which organisms can survive there.
6-8	The distribution of traits in a population can change when the environment changes.
9-12	Populations eventually become dominated by organisms best suited for their environment.

Adaptation is a response to environmental change that occurs over generations. Variation and natural selection and the processes that drive adaptation. Students begin this progression by observing that there are places on Earth where few or no living things can live. In late elementary school, this idea develops as students see that even though most places on Earth have some variety of organisms living there, no single place is suited for all of Earth's diversity. As a result, similar environments develop relatively similar collections of species. Changes to the environment may benefit new or different organisms, which can drive changes in the distribution of traits in a population. Different scales of change can lead to more significant effects on populations, including the emergence of new species.

K-2 Standards

By the end of grade 2. Living things can survive only where their needs are met. If some places are too hot or too cold or have too little water or food, plants and animals may not be able to live there. – NRC, 2012

Progression Across Grade Bands:

Adaptation is a process that occurs over time when there are changes to the place where an organism lives.

At the beginning of this progression, students should consider that some places have conditions where few or no organisms can survive. The factors that cause this may be too hot, too cold, too dry, or too little available food. The intent is for students to see that there are factors that might make it hard for organisms to survive in some places.

In the past, it might have been common to assign a habitat project address these ideas. Researching an organism to design a suitable habitat is not likely to address the ideas of this progression. Instead, consider asking students to investigate whether they find the same number of living everywhere around the school. By sampling different places around the school can see that very few things live in places like sidewalks or concrete pads. They can then study the features of these sites further to uncover how the conditions (being hot and dry) are different in these places, as opposed to the places where many things survive. Similar data across seasons can show the effect of cold on the number of organisms found around the school.

Knowledge- building attempts in early readers often improperly address this progression. For example, books might talk about how cold it is in the Arctic and show specific features that help animals survive the cold. While it is helpful for students to learn how extreme the conditions can be, the readers should address that there are very few different types of animals that can survive these conditions. Among the animals that can survive, there are very few individuals.

In later grades, students will see that even places where organisms live may not be suitable for all organisms to live there. This is a first step towards understanding that the process of adaptation has resulted in a collection of organisms in any given place that are best suited for that place. If the conditions in that place change, then after time the types and characteristics of organisms living there will change as well.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful. For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all. – NRC, 2012

Progression Across Grade Bands:

This progression began by considering that there are places where few or no living things survive because the conditions are too extreme in those places. Extremes might include being too hot or cold, too dry, or with too little food available. The goal was for students to understand that the conditions in a place influence whether organisms can live there.

The goal for the 3-5 grade band is for students to understand that even in places where organisms can live, not all organisms can live there, since no one place is suited to all types of life. Every different type of organism can only tolerate a limited range of conditions has a range of conditions. Since environmental conditions vary at different places, a relatively fixed collection of organisms live in each environment.

One way for students to uncover the connection between organisms and place would be to look at maps showing distribution data for a particular species compared with temperature and rainfall data for different locations. Students should see patterns where the distribution coincides with certain temperatures. Students could make claims and ask questions attempting to explain why the pattern exists. There will also be areas where students may expect to find the species, but it is not found. Students can develop and support claims to explain why the species is absent from those places.

The collection of organisms that live in a place is a result determined by the characteristics in that place and the unique tolerances and characteristics of different organisms. This means that when the environment changes the new conditions may not favor the same set of organisms.

In later grades, as part of component idea LS4.B, students will learn that natural selection causes the frequency of traits in a species to reach equilibrium in a population. Environmental changes may can upset this equilibrium when different traits cause some individuals to outperform others. Changes to any environment may be helpful or harmful to the organisms living there.

Current (2018 Implementation): 3.LS4.1, 3.LS4.2

3.LS4.1 – Explain the cause-and-effect relationship between a naturally changing environment and an organism's ability to survive.

Big Ideas:

Environmental change is inevitable. Changes to an environment will impact the organisms that live there.

Scientific Ideas:

- Living organisms depend on their surroundings to meet their needs.
- Organisms live only where their needs are met and where they can tolerate the physical conditions (temperature, sunlight, soil, wind, moisture, etc.).
- Environments change in a variety of ways including periodic changes and less predictable changes.
- Some of the organisms in that place may thrive in the new conditions.
- When the environment changes, the conditions may not favor the organisms that lived there previously, and the number of those organisms may decrease.
- It is possible that changes may result in conditions where some types of organisms may no longer live in that place.

Common Student Ideas:

- It is possible to prevent the environment from changing.
- Any changes to the environment will affect all the things that live there in the same way.
- ...

3.LS4.2 – Infer that plant and animal adaptations help them survive in land and aquatic biomes.

Big Ideas:

Organisms have different features and behaviors that may help them survive to different extents when the environment changes.

Scientific Ideas:

- Places on Earth have characteristics that make them unique – e.g., temperature, precipitation, being very wet or very dry, etc.
- Organisms can only survive in places where their needs are met and so each type of organism has a limited number of places where it can live.
- Environments have changed over time in ways that affect the types of organisms that live there. Any place on Earth will have a limited set of organisms that live there.
- Populations that have existed in a relatively stable environment will have structures and behaviors that help them survive in the conditions of that place.

- The collection of different species in a place may have similar strategies that have helped them survive in a place – e.g., multiple plant species lose their leaves in the winter, or a collection of species that migrate in and out of an area.

Common Student Ideas:

- Adaptations are structures. (Using the words adaptation and structure interchangeably.)
- All adaptations are physical changes to organisms.
- …

Revised (2025 Implementation): 3.LS4.1

3.LS4.1 – Use evidence to explain the cause-and-effect relationship between a naturally changing habitat and how well an organism survives.

6-8 Standards

By the end of grade 8. Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. In separated populations with different conditions, the changes can be large enough that the populations, provided they remain separated (a process called reproductive isolation), evolve to become separate species. – NRC, 2012

Progression Across Grade Bands:

Before this grade, students have uncovered two foundational ideas: no one place is suited to all types of living things, and changes to an environment may be beneficial or harmful. Middle school students are exploring the principle of natural selection in component idea LS4.bB. This component idea considers how changes to the environment drive the process of natural selection.

Adaptation is the process that occurs when natural selection acts on populations in response to environmental pressures. Traits that may have been favorable and common in an earlier environment may no longer be favorable in a changed environment. Over generations in a changed environment, a new set of characteristics may become common.

Students often use the word "adaptation" to describe a part of an organism. For example, they may say that the shape of a bird's beak is an adaptation. It is important that students learn that adaptation refers to a process that occurs over generations, despite the common use of the word to describe a part of an organism, rather than a process.

Middle school students can think about how different scales of environmental change influence adaptation. Sudden and dramatic changes may not provide enough time for a species to adapt, which can lead to the disappearance of a species. It is possible for adaptation to lead to the emergence of a new species if a population becomes divided and the two parts of the population live in environments with different conditions.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): 8.LS4.4

8.LS4.4 – Develop a scientific explanation of how natural selection plays a role in determining the survival and reproduction of a species in a changing environment.

9-12 Standards

Natural selection is the result of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. Natural selection leads to adaptation -—that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well- suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change.

Changes in the physical environment, whether naturally occurring or human-induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline —- and sometimes the extinction -— of some species. Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or too drastic, the opportunity for the species' evolution is lost. – NRC, 2012

Progression Across Grade Bands

The early portions of this progression help students understand that there is a connection between the environmental conditions and the living things in that place. This begins with the observation that some places can be so harsh that very few things can live there. Then students learn that changes to the environment can affect which organisms survive there.

In middle school, students learn that an organism's traits are a result of genes. Some variants of a trait can provide advantages to individuals. These individuals are more likely to survive, reproduce, and therefore pass their traits on to their offspring. Over generations, natural selection causes the advantageous traits to be passed on more often. The focus in middle school was on the trait, and not on the population.

High school standards discuss adaptation as a phenomenon that occurs at the scale of the whole population. Natural selection causes characteristics to become more common in a population when individuals with the beneficial characteristics have more offspring than individuals without the advantageous characteristics. Adaptation is a process driven by natural selection that leads, over time, to a population that is better suited to its environment.

When environmental conditions remain stable for long enough, a majority of the population will come to take on certain sets of characteristics. When environmental conditions remain stable long enough, most of the population will take on certain sets of characteristics. This idea connects back to earlier standards relating the environment to the organisms. In periods with frequent environmental disruption, there may not be time for natural selection to cause a particular characteristic to become dominant. Levels of disruption can be significant enough that species might not have capacity to adapt and will not survive in the changed environment.

A combination of factors must exist for adaptation to occur.

Revised (2025 Implementation): Bio1.LS4.3, Bio1.LS4.4

Bio1.LS4.3 – Analyze and interpret data that natural selection is influenced by (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

Big Idea(s):

Natural selection drives adaptation and is a result of several factors that must exist at once.

Scientific Ideas:

- A population consists of a group of the same species.
- Adaptation leads to populations where most organisms in a population possess those characteristics that provide the greatest advantages in their environment.
- Natural selection is the mechanism that results in populations that are adapted to their environment.
- Adaptation in a population can be tracked by changes in allele frequency.
- Rates of adaptation do not happen at a set or uniform rate. Different factors can affect how quickly adaptation happens.(happens. (Below)
- Sudden changes where the frequency of advantageous alleles increases indicate that a population is experiencing high selective pressures.

A species must have the potential to increase in number.

- Adaptations occur when favorable characteristics are passed from one generation to the next.
- A species that cannot reproduce will not be able to pass on favorable characteristics because future generations will not arise.

Rates are affected by the amount of heritable genetic variation in the species:

- Genetic variation refers to the number of different alleles in the gene pool of a population.
- New alleles arise in a population through mutations, or when individuals from other populations introduce new genes into the population.
- Low genetic variation in a population reduces a species' ability to adapt because there are less fewer possible outcomes to selective pressure.
- A variety of alleles in a gene pool increases the chances that some members might survive and that those genes will be inherited.

Rates are affected by interspecific and intraspecific competition.

- Competition is low when resources are abundant. Survival rates are high and most alleles in the population are maintained across generations.
- Competition is high when a population reaches its carrying capacity because there are no excess resources.
- Levels of competition are highest within a species (intraspecific competition) because individuals of the same species will have the most similar needs. The result is that intraspecific competition is the greatest contribution to allele shifts.
- Intraspecific is a less significant factor because the needs of individuals may not align as closely.

Common Student Ideas:

- Adaptations will always be physical parts (tail, talons, stems, etc.) on a plant or animal.
- Adaptations arise quickly.
- Adaptation is always caused by predator/prey relationships.

Bio1.LS4.4 – Construct an explanation based on evidence for how natural selection leads to adaptation in populations.

Big Idea(s):

Differences among organisms of the same species can provide advantages in survival and reproduction for some members. Over generations, the advantageous characteristic becomes prevalent in the population.

Scientific Ideas:

- An organism's physical and behavioral characteristics are determined, in part, by its genes.
- Genetic differences can lead to expressed differences between individual members of the same species.

- Some differences between individuals make it more likely that certain individuals – with greater fitness – will survive and reproduce relative to other individuals of the same species.
- An organism receives its unique combination of genes from its parents.
- When a particular advantage is encoded in an organism's DNA, then it is possible for that organism's offspring to inherit the advantage.
- If selective pressures in the environment remain relatively consistent, then offspring which that inherit an advantageous characteristic will also be more likely to survive and reproduce.
- Adaptation leads to advantageous characteristics becoming increasingly common in a population over time.
- Changes to the environment can favor different sets of characteristics and/or influence how quickly a characteristic becomes common throughout a population.
- Sexual selection for a trait will make that trait more common over generations.
- Selective pressures can lead to tradeoffs. Selection for a trait for one reason (e.g., sexual selection) can be detrimental for other reasons (e.g., harder to escape predators).

Common Student Ideas:

- There are differences between species, but not within the same species.
- If a parent possesses an advantageous characteristic, then their offspring will also (always) inherit the genes for that advantageous characteristic.

Neutral or disadvantageous characteristics disappear rapidly from populations when advantageous variations arise.

LS4.D: Biodiversity and Humans

Guiding Question:

What is biodiversity, how do humans affect it, and how does it affect humans?

The Biggest Ideas:

Purpose

Healthy ecosystems provide for the species living there, including humans. This strand explores the way that the health and stability of an ecosystem relate directly to its biodiversity.

Central Idea:

Humans are part of the environment. Our environment provides both resources and services. Healthy environments provide the most abundant and widest range of benefits. There are different scales to measure health – variety of genes in a population, variety of species in an ecosystem, or variety of ecosystems on Earth. These are all measures of biodiversity.

General Progression

Grade Band	Development
K-2	Close observation of a place reveals many different types of things living there.
3-5	Classification is a way to catalog diversity and enables scientists to see how changes to habitats affect the organisms living there.
6-8	Biodiversity includes the range of living things in a place. At different scales, it also includes a diversity of genes and ecosystems.
9-12	The health of Earth depends on diversity at a variety of levels (species, genetic, ecosystem) and human activities can have negative and positive impacts.

As students work through this progression, they expand their definitions of biodiversity in ways that mirror broader progressions. Students begin with informal discussions about the number of different types of living things in an area. When they learn about ecosystems, they can consider biodiversity based on having a variety of ecosystems on Earth. Finally, when they learn about genes, they consider biodiversity as measured by the variety of genes in a population of organisms. At all scales greater variety indicates greater biodiversity.

K-2 Standards

By the end of grade 2. There are many different kinds of living things in any area, and they exist in different places on land and in water. – NRC, 2012

Progression Across Grade Bands:

Even though young children are not likely to encounter the term "biodiversity," the idea refers to the different types of living things – ecosystems, plants, animals, microbes – that are essential for a healthy planet. The goal for young students is to appreciate that there are of many different types of living things in an area and living things can be found in a variety of different places. Students can explore their community and schoolyards creating a catalog of the different types of living things that they find there. Spending time in one space and making careful observations will allow students to observe plants and animals that are small and easily overlooked. Students will find that there are often many different types of plants, even in a place that appears to be just grass. These experiences will prepare students to understand the concepts of biodiversity and ecosystem health in later grades.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Scientists have identified and classified many plants and animals. Populations of organisms live in a variety of habitats, and changes in those habitats affect the organisms living there. Humans, like all other organisms, obtain living and nonliving resources from their environments. – NRC, 2012

Progression Across Grade Bands:

In early grades, students should have had opportunities to make careful observations of the variety of things living around them. These observations give students a sense that many different types of things live in a place – even when it's not obvious.

In later elementary grades, students continue to use and develop their skills of observation, but now the purpose is to make careful observations about individual organisms to understand that living things can be organized into groups. Classification provides a way to catalog the types of organisms living in a particular place. When the organisms in a place have been classified, it is possible to compare that place to other places where the same organism or group of organisms might be found. Classification lets us view Earth's biodiversity as a sort of account balance because it provides a way to quantify living things. In later grades, students will learn to view the emergence of new species as a deposit to this "account" while extinctions permanently lower this balance.

It is not necessary for students to memorize the levels of the Linnean Classification System or even to know simpler levels such as genus and species. At this grade level, the idea of biodiversity is uncomplicated and focuses primarily on whether an area has many different types of organisms living there.

Humans are a type of living organism with a set of needs just like all living organisms. Humans use their surroundings to meet their needs, just like other species. The types of resources provided by the environment should focus on tangible goods (food, water, air, shelter, etc.) that students are likely to be familiar with. In later grades, students will discuss services provided by healthy ecosystems – such as reducing the runoff of sediment into waterways.

Current (2018 Implementation): 3.LS4.3

3.LS4.3 – Explain how changes to an environment's biodiversity influence human resources.

<u>Big Ideas:</u>

Humans rely on their surroundings to meet their needs and the environment's ability to meet these needs depends on the variety of organisms that live there.

<u>Scientific Ideas:</u>

- Humans are a type of living organism and therefore depend on resources they obtain from their surroundings.
- Humans use both living (e.g., food, lumber, shade) and non-living (e.g., clean water, soil) resources from their surroundings.
- Scientists must keep track of the different types of organisms that live in a place to be able to describe the biodiversity of that place.
- Having high biodiversity means that there are many different types of living things in an area.
- Losing organisms from the environment also means losing the benefits that organism provides to the environment.
- Some plants and animals depend on each other and threats to biodiversity may impact both species even if only one type is directly harmed (e.g., pollinators, animals with limited food sources, loss of specific type of habitat/cover).

Common Student Ideas:

- There are some things that humans can make that do not use materials from the natural world.
- ...

Revised (2025 Implementation): 3.LS4.2

3.LS4.2 – Use evidence to determine the changes between an environment's biodiversity and human resources.

6-8 Standards

By the end of grade 8. Biodiversity is the wide range of existing life forms that have adapted to the variety of conditions on Earth, from terrestrial to marine ecosystems. Biodiversity includes genetic variation within a species, in addition to species variation in different habitats and ecosystem types (e.g., forests, grasslands, wetlands). Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. – NRC, 2012

Progression Across Grade Bands:

In earlier grades, students have explored the variety of living things in their immediate surroundings and seen that scientists keep track of the types of living things found on earth and the types of places where these organisms are found. In middle grades, students explore the idea of biodiversity at different scales.

Students learn that chromosomes contain genes. These chromosomes transfer genes from parent to offspring – accounting for similar characteristics between parents and their offspring. Each member of a species will have roughly the same number of genes, but each gene can have a variety of different alleles. Genetic variation represents a form of biodiversity within a species. A species with high levels of genetic biodiversity is going to be more resilient in the face of external pressures.

Students have considered tangible resources that a humans obtain from their surroundings. Middle school students can consider more abstract services provided by an ecosystem. Students should also explore specific ways that biodiversity has an impact on the ability of the environment to provide humans with the resources they need. This extends to the earlier idea that humans, like all organisms, depend on their environment.

Current (2018 Implementation): 6.LS4.1, 6.LS4.2

6.LS4.1 – Explain how changes in biodiversity would impact ecosystem stability and natural resources.

Big Idea(s):

Biodiversity is described at different scales. Processes that occur in ecosystems provide humans with the resources they need.

Scientific Ideas:

- Humans are a type of living organism and therefore depend on resources they obtain from their surroundings.

- Humans use both living and non-living resources from their surroundings.
- The things that humans take from the environment are a result of processes that occur in ecosystems (e.g., water purification, recycling matter in soils).
- Identifying and classifying living organisms is a way to describe biodiversity.
    - Areas with a large number of different types of organisms living there have high biodiversity.
    - Low biodiversity can mean that an area only has a few organisms living there, but also refers to areas with only a single type of organism living there. (e.g., growing only one crop in a field.
- Biodiversity can be described for both large and small places and it is possible to have areas of high biodiversity very close to areas with low biodiversity.
- Losing organisms from the environment also means losing the benefits that organism provides to the environment.
- Some plants and animals depend on each other and threats to biodiversity may impact both species even if only one type is directly harmed (e.g., pollinators, animals with limited food sources, loss of specific type of habitat/cover).
- Humans catalog a range of features about an ecosystem to describe its biodiversity (e.g., the type of ecosystem, species present, variety of traits within those species).
- Some of the resources that humans use come only from ecosystem types and losing those ecosystems results in the loss of those resources.

Common Student Ideas:

- Ecosystems are healthy and stable as long as an ecosystem has many things living there.
- …

6.LS4.2 – Design a possible solution for maintaining the biodiversity of ecosystems while still providing necessary human resources without disrupting environmental equilibrium.

Big Idea(s):

We must understand the ideas of biodiversity as well as engineering/problematizing practices to apply engineering practices to challenges related to biodiversity.

Scientific Ideas:

- Ideas from 6.LS4.1.
- Ecosystems experience constant changes (e.g., increase/decrease in population sizes, changes to habitat availability).
- Healthy ecosystems remain in a stable state where changes the effects of changes are damped and diminish over time without significant changes to the ecosystem conditions prior to the change.

- Designing solutions requires understanding the criteria for successful solutions as well as constraints that may limit the potential solutions.

Common Student Ideas:

- Any disturbance to an ecosystem will have long- lasting effects.
- …

Revised (2025 Implementation): 6.LS4.1

6.LS4.1 – Explain how changes to biodiversity in a system would impact human resources (e.g., food, medicine, and clean water) and "ecosystem services" (e.g., climate stabilization, decomposition of waste, and pollination).

9-12 Standards

Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Biological extinction, being irreversible, is a critical factor in reducing the planet's natural capital.

Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. These problems have the potential to cause a major wave of biological extinctions—as many species or populations of a given species, unable to survive in changed environments, die out—and the effects may be harmful to humans and other living things. Thus, sustaining biodiversity so that ecosystem function, and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. – NRC, 2012

Progression Across Grade Bands

In elementary grades, students learned that scientists use careful observations to classify living things. Classifying and cataloging living things make it possible for scientists to quantify biodiversity. In middle school, students learn about chromosomes and genetic diversity and think about biodiversity at different scales.

Extinction reduces levels of biodiversity. This is easier to understand when we think about the extinction of an entire species, but as population sizes decrease genetic diversity will suffer first. Smaller population sizes mean smaller gene pools and therefore certain alleles may be lost from the gene pool well before the species becomes extinct. This also means that the survivability of the species decreases because the expression of genetic variation is the means that allows the species to be resilient against environmental changes.

Speciation increases levels of biodiversity. Genetically, a new species emerges as members of an existing species become reproductively isolated. In other words, a subset of a species becomes genetically unique to the point that they are no longer able to produce viable offspring with members of the original population. The conditions that lead to speciation result in unique combinations of alleles. These pressures, therefore, increase both genetic and species diversity.

Changes to DNA can also lead to genetic diversity. Mutations that lead to the formation of new alleles. New alleles represent an increase in biodiversity.

A variety of things activities directly and indirectly affect levels of biodiversity. Humans can make design decisions that support biodiversity by preventing the loss of biodiversity or intentionally increasing biodiversity. Human activities can have neutral or negative consequences on biodiversity – often unintentionally.

Revised (2025 Implementation): Bio1.LS4.5

Bio1.LS4.5 – Obtain, evaluate, and communicate information about how changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

<u>Big Idea(s):</u>

Environmental changes – including those caused by humans – can lead to changes in Earth's biodiversity including species loss or emergence.

<u>Scientific Ideas:</u>

- Living things depend on living and non-living components in their environment. When the environment changes, some resources they depend on may become unavailable.
- Living things are only able to survive within a narrow range of conditions (e.g., temperature, sunlight, precipitation, pH, etc.)
- Human activity can cause changes to the conditions in an organism's habitat.
- A species is a group of organisms who that are reproductively isolated from other organisms.

Environmental changes can lead to the emergence of new species:

- A population consists of organisms belonging to the same species with a shared gene pool.
- The emergence of a new species begins when some factor causes portions of the population to become isolated. A new species' emergence begins when some factor makes portions of the population isolated.
- A variety of factors can cause isolation. The common outcome is that gene flow to a portion of the population differs and allele frequencies in each group can begin to diverge.
- Mutations can lead to the formation of new alleles in either group.
- Differences in selective pressures acting on each group cause differences in alleles to accumulate in ways that affect morphology, behavior, physiology, reproduction, etc.
- Eventually the two groups differ to such an extent that they are no longer able to interbreed. Eventually, the two groups differ so much that they are no longer able to interbreed.

Biodiversity

- Extinctions cause Earth's species diversity to decrease.

- Speciation causes Earth's species diversity to increase.

Common Student Ideas:

- Species can become extinct, but new species do not emerge.
- All species on Earth now have been on Earth since the planet formed.

ESS1.A: The Universe and Its Stars

Guiding Question:

What is the universe, and what goes on in stars?

The Biggest Ideas

PURPOSE

This strand explores the motion objects in the universe and formation and life cycle of stars which provide insights about the history of our universe and its contents.

CENTRAL IDEA(S):

The things in outer space are constantly changing - stars are being born and eventually die, galaxies move away from each other, etc. The patterns in the motion of galaxies and an understanding of gravity help us understand the history of the universe.

GENERAL PROGRESSION

The three component ideas of ESS1 cover three different spatial scales: the universe, the solar system, and the Earth, respectively. ESS1.A explores the history of the universe and its largest structures, such as galaxies and stars. In the earliest grades students focus on making observations about patterns they experience caused by the movement of things in space. After learning about gravity in physical science component ideas students can understand role gravity has played in the origin of both structures in space and the motion of objects in space.

K-2 Standards

By the end of grade 2. Patterns of the motion of the sun, moon, and stars in the sky can be observed, described, and predicted. At night one can see the light coming from many stars with the naked eye, but telescopes make it possible to see many more and to observe them and the moon and planets in greater detail. – NRC, 2012

Progression Across Grade Bands

Young students may not notice the ways that the sky changes. Some may recognize that the sun is not always in the same place or that the moon does not always look the same. The goal for this grade band is for students to have concrete experiences making observations about the sky and so that they begin to see that the things they see in the sky are in motion. Students are not expected to describe the cause the patterns they see.

In physical sciences, students are learning that light makes things visible. Students should understand that we see stars in the sky at night because of the light coming from the stars. Experiences with telescopes or images captured using telescopes allow us to see details about the sky. Students are not expected to learn about telescopes as devices. The intent is that students develop an appreciation that the sky there are way more things in the sky than we usually see.

In later grades, students will discuss the idea of space and that space is a vast open area that contains many different types of objects. The sun will be a point of reference as students begin to discuss space to help students begin to understand the size and relative emptiness of space.

Current (2018 Implementation): 1.ESS1.1, 1.ESS1.2

1.ESS1.1 – Use observations or models of the sun, moon, and stars to describe patterns that can be predicted.

Big Ideas:

We can describe all the ways that the sky changes. Some of these changes are easier to detect than other changes. [note: Observations should focus on the motion or change in position of objects in the sky and not on changes in the appearance of objects.]

Scientific Ideas:

- We can see things in the sky during the night and during the day.
- To describe motion or changes in position we need to use some object as a reference point (e.g., the moon appears close to the tops of those trees at sunset).

- The things that we see in the sky appear to move relative to objects on the Earth and relative to other objects in the sky (e.g., the sun looked like it was above me at lunchtime, but to the side of me at dinner time or the moon is close to that bright star now but was further away earlier).
- Some objects in the sky do not appear to be moving, but it is possible to see how their positions have changed if we make observations over longer periods of time.
- By looking at collections of observations about the sky, we can see patterns in the way that objects move (e.g., every morning this week I could see the sun near the top of that building when I got to school).
- When we describe patterns, it becomes possible to make predictions by using these patterns (e.g., In the morning the sun was near the top of that building. Now – at lunchtime – the sun looks like it is right over my head. I predicted that the sun was in this position two hours ago.)

Example(s) of Common Student Ideas:

- The sun is the only object in the sky that appears to move.
- The moon stays in the same place in the sky each night.

1.ESS1.2 – Observe natural objects in the sky that can be seen from Earth with the naked eye and recognize that a telescope, used as a tool, can provide greater detail of objects in the sky.

Big Ideas:

Technologies like the telescope allow humans to make more detailed observations about the night sky.

Scientific Ideas:

- Humans make observations using their senses.
- Technologies are tools and some technologies help us make observations that we could not make with our senses directly.
    - A pencil and paper or photographs allow us to record our observations to see how the sky changes over time.
    - Telescopes are a technology that improves our sense of sight.
- Telescopes help us see things that are far away by focusing the light coming from a smaller part of the sky.
- Telescopes allow us to see details in objects that our eyes could not detect.

Example(s) of Common Student Ideas:

- The things you see in the telescope viewing area are different from the things you see with your naked eye.
- …

Revised (2025 Implementation): 1.ESS1.1, 1.ESS1.2

1.ESS1.1 – Use observations or models of the sun, moon, and stars to describe patterns that can be predicted.

1.ESS1.2 – Observe natural objects in the sky that can be seen from Earth with the naked eye and recognize that a telescope, used as a tool, can provide greater detail of objects in the sky.

3-5 Standards

By the end of grade 5. The sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their size and distance from Earth.
– NRC, 2012

Progression Across Grade Bands

In earlier grades students made observations describing patterns in the motion and appearance of objects in the sky. A critical development in the 3-5 grade band is that students should learn that when they are looking at the sky, they are looking into space, not just looking at a flat surface.

Students are likely to feel that our star, the Sun, is a special star and they may also feel that it must be larger or more powerful than other stars. Students should understand that these perceptions are a result of our Sun's proximity. The distance from and size of the Sun should serve as a relative scale as students begin to develop a sense of the size of the universe.

By the middle grades, students will have a general understanding of gravity and of the motion of objects. By combining their understanding of the size and positions of objects in space they will begin to use models to explain how the movements of objects in space result in the patterns observed as early as K-2.

Current (2018 Implementation): 5.ESS1.1, 5.ESS1.2

5.ESS1.1 – Explain the differences in the apparent brightness of the sun compared to other stars is due to their relative distances from the Earth.

Big Ideas:

The sun is one of many stars and types of stars in the universe. *[Note: Students have not explored different elements. Discussions that associate color of light with star composition exceed grade level content.]*

Scientific Ideas:

- Stars are one type of object in space.
- Space has depth and the sky is not a flat surface above us.
- Stars shine because they release energy in the form of light.
- Some objects reflect the light produced by stars, but these objects are not stars (e.g., the moon).
- The Sun is a star.

- We feel the energy released by the Sun because light from the sun carries this energy to Earth.
- There are different types of stars.
- White light is a blend of all of colors of light (ROYGBIV)
- Different types of stars are classified based on the colors of light they produce.
- Scientists use diffraction gratings that they can use to look at the colors of light produced by a star.
- There are types of stars that are larger than our sun.
- We can measure and compare the size of other stars relative to the size of the sun.
- We can measure distances to and between objects in space relative to our distance to the sun.
- Objects appear larger when they are close to us compared to when they are further away.
- Stars appear larger or smaller depending on how close they are to our planet. Our sun appears to be so much larger than other stars because it is closer than other stars.
- The sun is close enough to produce the phenomena of night and day because of its proximity, whereas we see the light from other stars, but the distance is too great for these stars to create daylight.

<u>Example(s) of Common Student Ideas:</u>

- Our sun is the biggest star.

5.ESS1.2 – Research and explain the position of the Earth and the solar system within the Milky Way galaxy and compare the size and shape of the Milky Way to other galaxies in the Universe.

<u>Big Ideas:</u>

The Milky Way Galaxy is one of countless galaxies in space. Scientists can make observations about these different types of galaxies.

<u>Scientific Ideas:</u>

- Earth is a planet within our solar system, which is part of our interstellar neighborhood within the Milky Way Galaxy.
- There are many galaxies in space and more of these galaxies are visible when observed further from light sources on Earth.
- Because of gravity, galaxies are grouped in space rather than a random distribution in space.
- Galaxies are classified by their shape.
- Gravity causes galaxies to begin with an elliptical shape [note: This elliptical shape does not mean that all galaxies begin as elliptical galaxies.

- The spinning motion of a galaxy causes it to take a flattened shape.
- Since the materials at the center of a galaxy spin more slowly, this part of the galaxy does not flatten out as much.
- Depending on the types of materials (gas, dust, etc.) and the distribution of these materials, the galaxies will take different shapes as they form.
- Stars and galaxies come together in unison as gravity acting on matter is the cause of each of these systems.

Example(s) of Common Student Ideas:

- Humans have taken pictures of the Milky Way galaxy.

Revised (2025 Implementation): 5.ESS1.1, 5.ESS1.2

5.ESS1.1 – Explain that differences in the apparent brightness of the sun compared to other stars are due to their relative distances from the Earth.

5.ESS1.2 – Research and explain the position of the Earth and the solar system within the Milky Way galaxy and compare the size and shape of the Milky Way to other galaxies in the universe.

6-8 Standards

By the end of grade 8. Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models. The universe began with a period of extreme and rapid expansion known as the Big Bang. Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe. – NRC, 2012

Progression Across Grade Bands

In the middle grades, students transition from observations about the sky and space to explanations about the sky and space. Students have observed patterns that occur in the sky and learned about relative sizes and distances between objects in space.

By middle grades, students have an understanding of gravity as a force (PS2) and that matter is made of a limited number of elements (PS1). Students apply their understanding of gravity to using models to account for our observations of the motion of objects in the sky. Understanding the properties of light and how waves are affected by motion objects, students can support that the universe came into existence from a single point at a single moment in time.

Current (2018 Implementation): 8.ESS1.1

8.ESS1.1 – Research, analyze, and communicate that the universe began with a period of rapid expansion using evidence from the motion of galaxies and the composition of stars.

<u>Big Idea(s):</u>

Our observations about objects in space can be explained using models that describe how our universe was once a small point that began to expand outward in a single instant.

<u>Scientific Ideas:</u>

- Atoms have mass and therefore the force of gravity will pull atoms together.
- Stars form when gravity causes gases in space to accumulate and draw more gas inward.
- As stars gather more material, they become more massive. Their gravitational pull becomes stronger, and the gases drawn inward arrive at faster speeds.
- Eventually, the gases arrive with so much speed that they collide and two atoms of hydrogen fuse.
- Elements other than hydrogen form inside of stars:
    - Fusion of hydrogen atoms (nuclei) forms helium atoms and releases large amounts of energy.

    - Over time stars have produced more helium.
    - Larger stars are able to fuse larger types of atoms, such as helium to make slightly heavier elements, but the heaviest elements form when very large stars become supernovas and provide conditions where heavy nuclei can fuse.
- The light coming from stars helps us understand what elements they contain:
    - When they are energized, atoms produce light.
    - There are many different colors (wavelengths) of light.
    - Every different element produces a different color of light – has a unique "signature."
    - The colors of light coming from a star can be "decoded" to figure out what elements it contains.
    - These observations support the different types of stars that we see in space.
- The light coming from stars helps us understand the movement of stars and galaxies through the universe:
    - The size of a star determines which elements it can fuse. The "smallest" stars only have enough mass to fuse hydrogen nuclei together. As stars become more massive or as more massive stars are born, they are able to fuse the nuclei of heavier elements.
    - Because each element has a unique "signature" of light the colors of light coming from stars are predictable.
    - When a wave source is moving, the wavelengths it emits are stretched if the waves move in the opposite direction of the source or compressed if they are moving in the same direction as the source.
    - The wavelengths of the light that reaches us on Earth are longer than the predicted wavelengths of light from distant stars.
    - The stretching of the light from distant stars and galaxies is evidence that every object in the universe is moving away from the Earth.
    - This observation supports that the universe began from a single point as the inertia of the objects continues to move them away from this single point.

<u>Example(s) of Common Student Ideas:</u>

- We can see galaxies moving through space.
- Large objects in space do not move.
- The Solar System does not move in space.

Revised (2025 Implementation): 8.ESS1.1

8.ESS1.1 – Research, analyze, and communicate that the universe began with a period of rapid expansion using evidence from the motion of galaxies (i.e., redshift and blueshift), elemental concentrations of hydrogen and helium, and cosmic background radiation.

ESS1.B: Earth and the Solar System

Guiding Question:

What are the predictable patterns caused by Earth's movement in the solar system?

The Biggest Ideas

PURPOSE

This component idea helps students understand the role of gravity in the formation of the solar system and various phenomena on Earth caused by the movement and positions of objects in the solar system.

CENTRAL IDEA(S)

Gravity – the attractive force between matter of all sizes – was the force that brought together bits of gas, dust, and rock leading to the formation of our solar system. Gravity governs the motion of objects in the solar system which cause phenomena on Earth such as seasons, cycles of day and night, phases of the moon, tides, etc.

GENERAL PROGRESSION

The three component ideas of ESS1 cover three different spatial scales: the universe, the solar system, and the Earth, respectively. ESS1.B explores the observable patterns in the solar and its largest structures, such as the Sun, Moon, and planets. This progression begins by providing students with structures and opportunities to observe changes that occur through the seasons – similar to ESS1.A. The most important of these changes relating to sunrise and sunset. In later grades students observe a larger collection of patterns caused by interactions between the Sun, Earth, and the Moon. These observations serve are made to provide evidence that the Earth rotates on its axis. A complete view of the solar system emerges in middle school when it becomes possible to apply an understanding of gravity and conservation laws to explain the motion of the things in the solar system and associated phenomena experienced on Earth.

K-2 Standards

By the end of grade 2. Seasonal patterns of sunrise and sunset can be observed, described, and predicted. – NRC, 2012

Progression Across Grade Bands

In the earliest grades we want students to observe that sunrise and sunset do not occur at the same time each day and that it is possible to see patterns in the times that occur year after year. It may be helpful to use representations related to sunrise, sunset, and the length of the day. Students may relate day-length to seasonal conditions like warmer weather in the summer, but it is not essential to make that connection, since day length is only one of the factors that causes seasonal temperature differences. These observations did not require students to understand that the Sun is an object in space, nor that the Earth's rotation causes sunrise and sunset. Students only needed to understand that the sun provides the light that creates daylight.

The new idea for the 3-5 grade band is that objects like the sun and moon existing in space, not just on a flat sky. By middle school students will be able to apply their understanding of gravity to explain the motion of the planets and phenomenon such as a cause for the seasons.

Current (2018 Implementation): 1.ESS1.3

1.ESS1.3 – Analyze data to predict patterns between sunrise and sunset, and the changes of the season.

Big Ideas:

Sunrise and sunset happen at different times throughout the year, but across years there are patterns for the timing of these events.

[boundary: Focus is on changes to daylength, not changes to weather.]

Scientific Ideas:

- Sunset and sunrise where students live do not happen at the same time each day.
- The length of daylight changes where students live.
- There are patterns in the length of days where students live (e.g., successive days and days near each other have similar lengths, days that are further away may have different lengths, there are days of equal length at different times during the year).
- Data from multiple years can show that day length correlates with changes in the seasons – Days are shorter in the winter and longer in the summer, places on earth with greater differences in day length.

Example(s) of Common Student Ideas:

- For each day, there are 12 hours of daylight and 12 hours of night.

Revised (2025 Implementation): 1.ESS1.3

1.ESS1.3 – Make observations to predict patterns between sunrise and sunset, and the change of seasons.

3-5 Standards

By the end of grade 5. The orbits of Earth around the sun and of the moon around Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily and seasonal changes in the length and direction of shadows; phases of the moon; and different positions of the sun, moon, and stars at different times of the day, month, and year.

Some objects in the solar system can be seen with the naked eye. Planets in the night sky change positions and are not always visible from Earth as they orbit the sun. Stars appear in patterns called constellations, which can be used for navigation and appear to move together across the sky because of Earth's rotation. (NRC, 2012)

Progression Across Grade Bands

In early elementary, students uncovered patterns in the length of days through the year. While some students may be able to relate this to seasonal temperature changes, the focus was on daylength.

The new idea for the 3-5 grade band is that objects like the sun and moon existing in space, not just on a flat sky. Once students understand that outer space is a three-dimensional area, they are prepared to think about the movements of objects in space. Students begin with a limited set of moving objects – the relative positions of the Earth, Moon, and Sun can explain numerous phenomena, while the motion of a small set of constellations compared to the North Star are evidence that the Earth rotates on its axis. Using this small number of objects, students should practice working with model systems to explain the cause for these phenomena.

Current (2018 Implementation): 3.ESS1.1, 4.ESS1.2, 5.ESS1.3, 5.ESS1.4, 5.ESS1.5, 5.ESS1.6

3.ESS1.1 – Use data to categorize the planets in the solar system as inner or outer planets according to their physical properties.

Big Ideas:

There are patterns in the properties of planets depending on their location.

Scientific Ideas:

- All planets in the solar system move around the Sun.

- The paths of the planets have orbits that are nearly circular. [*Note: Avoid emphasizing the elliptical/oval shape of orbits as it is likely to generate misconceptions. Students may incorrectly believe that warm summer temperatures happen because the Earth gets closer to the Sun.*]
- The light from the Sun warms up everything in the solar system.
- The warming effect of the Sun decreases the further you get from the sun. [*Note: This effect is observable at planetary distances, but does not apply at distances on Earth – effectively, the poles and equator are equal distance from the Sun.]*
- When solids warm up, they will melt and when liquids warm up, they will become gas.
- Gas particles move quickly and spread out because particles bump into each other.
- It is too warm near the Sun for planets closer to the Sun to have icy rings.
- The planets that are close to the Sun are made of different metals that are hard to melt.
- Because these metals are hard to melt, they have remained solid even though the inner planets are relatively warm. This explains the rocky surfaces of the inner planets.
- The planets that are further from the Sun are cooler. These planets are made of liquid and frozen materials that would vaporize at temperatures closer to the Sun.

  [*Boundary: Students will not learn about specific elements (e.g., Hydrogen, Helium, Silicon, Iron) or compounds (e.g., methane) until middle school*.]

<u>Example(s) of Common Student Ideas:</u>

- Water is always a liquid.
- Materials are always either a solid, a liquid, or a gas regardless of temperature.
- The Sun warms up all the planets equally.

4.ESS1.2 – Use a model to explain how the orbit of the Earth and Sun cause observable patterns: a. day and night; b. changes in the length and direction of shadows over a day.

<u>Big Ideas:</u>

Models that can account for changes to shadows created by the Sun over days and months inform our understanding of the earth's spin on a fixed axis.

<u>Scientific Ideas:</u>

- Day/Night
    - The sun produces light and that light is able to travel through space.
    - The sun continues to produce light even when we are in a location on Earth where the sun cannot reach us.
    - Rays of light travel in straight lines.
    - The rays of light that reach Earth's surface are parallel to each other because of the Sun's size and distance from Earth.

    - At any point in time, the sun shines on half of the Earth's surface.
    - Light rays are not able to travel through the Earth and therefore the opposite side of the Earth is in a shadow caused by the Earth.
    - The Earth is spherical and spins on a fixed axis.
    - Daytime is a phenomenon that occurs when a location on Earth is within the illuminated half of the Earth.
    - Night is a phenomenon that occurs when a location on Earth is within the Earth's shadow.
    - Sunrise occurs as a location on Earth moves from the side of the Earth that is in shadow to the portion of the Earth that is illuminated.
    - Sunset occurs as a location on Earth moves from the illuminated side of the Earth into to the portion of the Earth that is in shadow.
- Changes to direction and length of shadows:
    - The earth spins on a tilted axis and travels around the sun. These two factors lead to changes in shadows visible over days as well as the year.
    - Rays of light travel in straight lines.
    - An object produces a shadow on a surface when it blocks rays of light and prevents those rays from reaching a surface.
    - Shadows will always appear on the opposite side of an object as the light source.
    - The rays of light that reach Earth's surface are parallel to each other because of the Sun's size and distance from Earth.
    - The shadow created by an object is longest when the light source (sun) is to the side of the object and shortest when the light source (sun) is directly above the object.
    - Each day a shadow is longest near sunrise and sunset, and shortest when the sun is at its highest point in the sky.
    - Over the course of the year, the length of a shadow will change when measured at the same time each day – the shadow will be shortest in the summer and longest in the winter.
    - There is a "path" that can be traced for locations where the sun is perfectly overhead on any given day. This path is not constant but moves between the Tropics of Cancer and Tropics of Capricorn over the course of the year.
    - Objects located along this "path" will have the shortest shadows relative to other locations on Earth's surface.
    - Objects closer to this path on a given day will have shorter shadows than objects further from this path.
    - The Earth's spin on a tiled axis accounts for these changes to the length of shadows over the course of months.

<u>Example(s) of Common Student Ideas:</u>

- The sun is always directly above the equator.

- It is possible to explain changes to the length of shadows over months without a tilt to the Earth's axis.

5.ESS1.3 – Use data to categorize different bodies in our solar system including moons, asteroids, comets, and meteoroids according to their physical properties and motion.

Big Ideas:

Gravity and prior motion cause the orbits of different bodies in the solar system and explain the physical properties of these bodies.

Scientific Ideas:

- Descriptions of an object's motion include both a speed and a direction.
- The motion of an object – speed and direction – will be constant unless it experiences a system of unbalanced pushes or pulls.
- Pushes in the direction of an object's motion will speed it up, pushes against an object's motion will slow it down, and pushes from the side will cause the object to turn, but not change speed.
- The force of gravity pulls together any objects/particles that have mass.
- Gravity is a field force – objects do not need to touch to experience pushes and pulls from gravity.
- The gravitational field force pulls towards the center of mass
- Orbits are a combination of two factors: pre-existing motion that is in a straight line and a centrally directed force that causes the motion to curve.
- The inward directed force of gravity by a planet keeps a moon in its orbit. These orbits are nearly elliptical.
- The inward directed force of gravity by the Sun maintains the orbit of a comet.
- The orbit of a comet is very elliptical, with a large amount of the time spent far from the Sun.
- The gravitational pull of the Sun on a comet causes a comet to speed up as it approaches the Sun and slow down as it moves away from the Sun.
- Asteroids orbit the Sun in a region of space called the asteroid belt.
- The orbital path of asteroids are nearly circular.
- Meteoroids are debris shed from other objects in space. Most meteoroids are broken off of asteroids, a smaller number come from mars and the moon.

Example(s) of Common Student Ideas:

- Everything in the solar system orbits the sun.
- All orbits are circles.

5.ESS1.4 – Explain the cause and effect relationship between the positions of the sun, earth, and moon and resulting eclipses, positions of constellations, and appearance of the moon.

Big Ideas:

Explanations for phenomena involving interactions between the Sun, Moon, Earth, and stars help us understand the movement and arrangement of objects in space.

Scientific Ideas:

- General ideas for all topics:
  - Stars produce light, but planets and the moon reflect the light from stars.
  - Rays of light travel in straight lines.
  - Rays of light from the Sun are parallel when they reach the Earth because of the immense distance between the Earth and Sun.
  - Nighttime occurs when light from the Sun does not reach the backside of Earth.
  - Objects that do not allow light to pass through them will produce a shadow.
- Eclipse details:
  - Eclipse systems involve the Sun, Earth, and Moon.
  - Eclipses occur when either the moon or the Earth blocks the light from the sun and one object falls into the shadow of the other object.
- Positions of constellations:
  - During the daytime, stars are not generally visible because the Sun is closer.
  - Relatively dimmer stars in the sky become visible at night.
  - In the northern hemisphere, the north star is visible in approximately the same position in the night sky throughout the night and year.
  - The relative positions of constellations over the course of an evening support claims that the Earth rotates around a fixed axis.
  - Different constellations are visible from each hemisphere.
  - Different constellations are visible in different seasons.
  - Differences in the portion of the night sky that are visible throughout one night and in different seasons support claims that the Earth orbits around the sun.
- Appearance details: *[Note: the intent of this standard is not for students to memorize the phases of the moon.]*
  - The moon does not make light, it appears to “light up” the night sky because it reflects the light from the sun.
  - The shape of the moon does not change – it is always spherical.
  - It is possible to determine the relative positions of the sun, moon, and an observer on Earth based on the appearance of the moon at night.
  - The moon has a light side where the sun shines and a dark side where the sun does not shine directly. *[Note: tidal locking exceeds the expectations of this standard]*

Example(s) of Common Student Ideas:

- The moon shines because it produces light.

5.ESS1.5 – Relate the tilt of the Earth's axis, as it revolves around the sun, to the varying intensities of sunlight at different latitudes. Evaluate how this causes changes in day-length and seasons.

Big Ideas:

Summer in each hemisphere occurs when more of the Sun's rays shine directly on that hemisphere, which is also when days are the longest in that hemisphere. During the winter, the inverse is true.

Scientific Ideas:

- Rays of light transfer energy from the Sun to Earth's surface and warms the Earth's surface.
- Rays of light travel in straight lines and these rays are parallel when they reach Earth's surface because the Sun is so far from the Earth.
- Rays of light are most concentrated when they strike a surface that is perpendicular to their direction of travel (i.e., rays that shine directly on a surface).
- Rays of light are less concentrated when they reach a surface that is not perpendicular to their direction of travel (i.e., rays that shine on a surface at an angle).
- Direct rays of light transfer more energy to Earth's surface than indirect rays of light.
- Day-length varies throughout the year.
- The Earth spins on a tilted axis and this tilt can explain variation in the length of days.
- More direct rays from the Sun fall north of the equator during some months because of the tilt of Earth's axis.
- Longer days and an increased number of rays striking the Earth's surface cause increased temperatures during some months.

Example(s) of Common Student Ideas:

- The sun always shines directly on the equator.

5.ESS1.6 – Use tools to describe how stars and constellations appear to move from the Earth's perspective throughout the seasons.

Big Ideas:

Patterns in the appearance and arrangement of stars can be captured and recorded. Models that explain these patterns support claims that the Earth travels around the sun over the course of a year.

Scientific Ideas:

- Positions of constellations:
    - During the daytime, stars are not generally visible because the Sun is closer.
    - Relatively dimmer stars in the sky become visible at night.
    - In the northern hemisphere, the north star is visible in approximately the same position in the night sky throughout the night and year.
    - The relative positions of constellations over the course of an evening support claims that the Earth rotates around a fixed axis.
    - Different constellations are visible from each hemisphere.
    - Different constellations are visible in different seasons.
    - Differences in the portion of the night sky that are visible throughout one night and in different seasons support claims that the Earth orbits around the sun.

<u>Example(s) of Common Student Ideas:</u>

- Constellations are visible all year long.

Revised (2025 Implementation): 5.ESS1.3, 5.ESS1.4, 5.ESS1.5, 5.ESS1.6

5.ESS1.3 – Use a model to explain how the orbit of the Earth and sun cause observable patterns: a. day and night; b. changes in length and direction of shadows over a day.

5.ESS1.4 – Explain the cause and effect relationship between the positions of the sun, earth, and moon and resulting eclipses, tides, and appearance of the moon.

5.ESS1.5 – Relate the tilt of the Earth's axis, as it revolves around the sun, to the varying intensities of sunlight at different latitudes. Evaluate how this causes changes in day-lengths and seasons.

5.ESS1.6 – Use tools to describe the position of constellations and how they appear to move from the Earth's perspective throughout the seasons.

6-8 Standards

By the end of grade 8. The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. This model of the solar system can explain tides, eclipses of the sun and the moon, and the motion of the planets in the sky relative to the stars. Earth's spin axis is fixed in direction over the short term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.

Progression Storyline:

Students began this progression by evaluating sunrise and sunset data showing how day lengths change throughout the seasons. In late elementary students began to think of space as a three-dimensional area where objects like the Earth, Moon, Sun, and stars can be found.

By middle school, students have a more developed understanding of forces where gravity is one of those forces that pulls things together. This helps students begin to develop explanations for Kepler's observations about the motion of the planets and the formation of the solar system.

Current (2018 Implementation): 8.ESS1.2

8.ESS1.2 – Explain the role of gravity in the formation of our sun and planets. Extend this explanation to address gravity's effect on the motion of celestial objects in our solar system and Earth's ocean tides.

<u>Big Idea(s):</u>

The force of gravity explains the formation and motion of objects in the solar system as well as Earth's tides.

<u>Scientific Ideas:</u>

- The different elements found on Earth form in stars or when stars explode.
- Gravity is a force that pushes or pulls any objects together.
- All objects with mass will experience the force of gravity – including individual atoms.
- As atoms concentrate at a single location, that gravitational force at that location will grow stronger.
- As gravity pulls more materials towards the central location, a cloud of dust and gases forms.
- Materials in space are already moving relative to each other.

- As moving materials are drawn towards a location where their concentration is already increasing, the group of materials will begin to orbit the central location in a single direction.
- The central star of a solar system forms when gravity has drawn a critical amount of material towards the center of the solar system.
- Every object within the collection of spinning materials is attracted to every other object in the collection – like bonds within pizza dough.
- The combination of the spinning motion of the materials and the attraction between the materials causes the cloud or materials to flatten – like spinning pizza dough.
- Gravity continues to draw objects together within the rotating disk accounting for the formation of planets where materials accumulate away from the central star.
- Planets are objects that have a large enough gravitational pull to have pulled in materials that fall within their orbital path.
- Planets have moons that orbit around them.
- Tides on Earth:
    - Patterns in the tides on Earth provide evidence that the Sun and Moon are sufficiently large, and their forces act over distances in space.
    - Liquids (and all fluids) are affected by pushes and pulls caused by gravity (e.g., water remains in the bottom of a glass).
    - Over a 24-hour period, water reaches different points at the shore of the ocean or other very large bodies of water.
        - During some parts of the day water moves "up the beach" – towards the place where a person might sit in the sand or into harbors causing boats and docks to rise.
        - During other parts of the day, water moves away from where people might sit in the sand, or out of harbors, causing boats and docks to lower.
        - A pattern exists where the tide comes in twice a day and goes out two times each day.
    - Observations of the position of the Sun and Moon show a correlation between the position of these objects and the changing tides.
    - Models which incorporate the force of gravity can explain the correlation between the positions of the Sun and Moon and the relative changes and strengths of tides.

<u>Example(s) of Common Student Ideas:</u>

- Only large objects – animals, planets are affected by gravity.

Revised (2025 Implementation): Overlap with 5.ESS1.4, 5.ESS1.5

ESS1.C: The History of Planet Earth

Guiding Question:

How do people reconstruct the dates and events in Earth's planetary history?

The Biggest Ideas

PURPOSE

This component idea helps students understand how scientists interpret the layers of sediment, rock formations, and fossils to tell the history of planet Earth.

CENTRAL IDEA(S)

Every different type of rock forms through a process that is unique to that rock type and has been consistent throughout Earth's history. Gradual and sudden events create features in Earth's rock layers. Scientists analyze the arrangement and type of rock layers to determine a sequence for the events Earth's past. Radioactive dating provides an approximate age of rocks which makes it possible to approximate when events occurred.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

The three component ideas of ESS1 cover three different spatial scales: the universe, the solar system, and the Earth, respectively. ESS1.C helps students understand how layers of rock tell the history of Earth. Students begin this progression by understanding that Earth experiences a variety of events. In late elementary school students learn that processes and events leave evidence in layers of rock and by middle school students are learning how to interpret maps and rock layers to understand specific types of features that tell us about Earth's past.

K-2 Standards

By the end of grade 2: Some events on Earth occur in cycles, like day and night, and others have a beginning and an end, like a volcanic eruption. Some events, like an earthquake, happen very quickly; others, such as the formation of the Grand Canyon, occur very slowly, over a time period much longer than one can observe. – NRC, 2012

Progression Across Grade Bands

This progression is about telling the story of Earth's history. A timeline for Earth's history includes numbers and dates that go beyond Tennessee's math standards for grades K-2. The idea of an "event" that changes Earth's surface is the critical element in this grade band. Students should come to understand that there are many different types and that some happen quickly, but other events last longer. Students may understand this by thinking about events in their own lives. Events like having a birthday or waking up are quick and sudden like earthquakes and volcanoes, while events like kindergarten or being seven years old happen over longer periods of time like the formation of the Grand Canyon. It is not necessary for students to consider how these events become preserved in layers or rock.

Late elementary and middle school together allow students to interpret both short- and long-term events in Earth's history. First, students will begin to think about how some events, such as weathering and erosion, lead to the formation of landforms and the way that these landforms are preserved as new layers of rock form above them and events such as earthquakes disturb layers that have already formed. Middle school students begin to think about the scale of geologic time and the formation of features that occur over these enormous periods of time – such as ocean basins and mountain ranges.

Current (2018 Implementation): 2.ESS1.1

2.ESS1.1 – Recognize that some of Earth's natural processes are cyclical, while others have a beginning and an end. Some events happen quickly, while others occur slowly over time.

<u>Big Ideas:</u>

The Earth experiences many different types of events, and we can categorize these events based on how long they last as well as whether they occur in cycles.

<u>Scientific Ideas:</u>

- The Earth experiences many different events.
- Some events happen in cycles (e.g., day/night, seasons, tides).

- Isolated events have a beginning and an end (e.g., volcanic eruptions, earthquakes, floods) and can quickly change Earth's surface (e.g., the formation of Reelfoot Lake).
- Some things that happen on Earth take a very long time (e.g., the formation of various Tennessee features: Twin Arches, Lost Cove Cave, Fall Creek Falls)

Example(s) of Common Student Ideas:

- The Earth only changes when there are sudden events like volcanoes, tornadoes, etc.

Revised (2025 Implementation): 2.ESS1.1

2.ESS1.1 – Recognize that some of Earth's natural processes are cyclical, while others have a beginning and an end. Some events happen quickly, while others occur slowly over time.

3-5 Standards

By the end of grade 5. Earth has changed over time. Understanding how landforms develop, are weathered (broken down into smaller pieces), and erode (get transported elsewhere) can help infer the history of the current landscape. Local, regional, and global patterns of rock formations reveal changes over time due to Earth forces, such as earthquakes. The presence and location of certain fossil types indicate the order in which rock layers were formed. Patterns of tree rings and ice cores from glaciers can help reconstruct Earth's recent climate history. – NRC, 2012

Progression Across Grade Bands

Students should have a general sense that there are a variety of "events" happen on which happen at a variety of rates, and cause changes to Earth's surface.

The biggest development in grades 3-5 is the idea Earth's rock layers preserve a record of past events. Sedimentary rocks form layer by layer and begin to create a record of Earth's history. The type of sediment and fossils preserved within the layers of sediment preserve a sequence of events and offer a sense of scale (size and duration) to Earth's history. Disruptions within otherwise orderly layers of sediment preserve a record of different events. A basic understanding of weathering and erosion will help students understand how sedimentary rocks form.

In middle school students will begin to apply their understanding of how to interpret Earth's rock layers in order to begin to evaluate the way that rock layers help scientists piece together specific events and large-scale features from Earth's past.

Current (2018 Implementation): 4.ESS1.1, 5.ESS1.7

4.ESS1.1 – Generate and support a claim with evidence that over long periods of time, erosion (weathering and transportation) and deposition have changed landscapes and created new landforms.

<u>Big Ideas:</u>

Wind and water rearrange materials in a way that wears down landforms in some areas and accumulates materials in other areas.

[Note: 4.ESS1.1 and 4.ESS2.1 both center on the idea that wind and water reshape Earth's surface. However, this bigger idea serves a different purpose under each standard. 4.ESS1.1 intends for students to understand that these processes are very gradual and large-scale effects of these processes that create landforms occur

over extremely long spans of time. 4.ESS2.1 intends for students to see that the changes to Earth's surface are caused by other systems and that the landforms, in turn, have effects on other systems.]

Scientific Ideas:

- Rocks and Earth's surface are not permanent. They can be broken into smaller pieces – boulders, rocks, pebbles, sand, etc. *[Note: These are not intended as technical examples – only examples of different sizes that may already be familiar to students.]*
- Slow transfers of energy result in gradual changes to the geosphere.
- Earth's surface has looked different throughout its history.
- Changes to Earth's surface can occur so slowly that they may not be observable firsthand.
- Gradual changes are a result of small energy changes accumulating over time. E.g., A single grain of sand being transported down a hill is a very small energy change. Over time, the collective movement of many grains of sand accounts for a very large change in energy and forms larger noticeable features.
- Earth's surface is made of many different types of materials (rocks, minerals, and soils. *[note: Students are not expected to learn different types of rocks/minerals or how they form.]*
- Different types of earth materials have different physical properties (e.g., hardness).
- Wind and water are forces that can move bits of rock and sediment.
- Landforms may arise where there are differences in the physical properties of adjacent rock types (e.g., caves form where rocks dissolve more easily, canyons form in places where softer materials are more easily broken down and transported by water).
- Landforms may form where materials accumulate over time.
- Changes to individual bits of rock and sand happen quickly because the smaller rocks can be impacted by smaller transfers of energy, but the accumulation of these changes that create new landforms happens slowly.
- Landforms from long ago may become visible as humans or natural forces expose new rock. These landforms may indicate how weathering/erosion/deposition played a role in that place's past.

Example(s) of Common Student Ideas:

- Erosion does not create new landforms.

5.ESS1.7 – Use evidence from the presence and location of fossils to determine the order in which rock strata were formed.

Big Ideas:

The presence and location of certain fossil types can tell us the sequence that layers of rock were formed.

Scientific Ideas:

- Some organisms that once lived on Earth are no longer alive today – some organisms became extinct.
- Fossils are evidence of different types of organisms that once lived, including many types of organisms that are no longer found on Earth.
- When an organism dies and its remains are left undisturbed, it is possible for that organism remains to be transformed into a fossil over extremely long periods of time.
- The remains of an organism form fossils when they are covered by layers of broken bits of rock and remain covered for extremely long periods of time.
- Fossils form in areas where water exists or where water transports broken bits of rock (e.g., river valleys).
- Layers of broken rock get deposited on top of each other so that the oldest layers occur on the bottom and newer layers pile on top. *[Note: disturbances to strata can occur but are beyond the expectation of the standard.]*
- New layers of rock form very slowly compared to the time that a type of organism is found on Earth.
- Once a species has become extinct, it is not possible for new fossils of that species to begin to form.
- Fossils of the same type of organism that occur in different places provide evidence that the rocks in which the fossils were found are similar age.

Example(s) of Common Student Ideas:

- Fossils are bones, not rocks.

Revised (2025 Implementation): 4.ESS1.1, 4.ESS1.2

4.ESS1.1 – Generate and support a claim with evidence that over long periods of time, erosion (i.e., weathering and transportation) and deposition have changed landscapes and created new landforms.

4.ESS1.2 – Use evidence from the presence and location of fossils to determine the order in which rock strata were formed.

6-8 Standards

By the end of grade 8. The geological time scale interpreted from rock strata provides a way to organize Earth's history. Major historical events include the formation of mountain chains and ocean basins, the evolution and extinction of particular living organisms, volcanic eruptions, periods of massive glaciation, and development of watersheds and rivers through glaciation and water erosion. Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale. – NRC, 2012

Progression Across Grade Bands

This progression began with students developing an understanding of the variety of "events" that lead to changes to Earth's surface. Later students begin to understand that the Earth's surface changes constantly. The formation of new rocks preserves a record of past events and conditions on Earth.

The biggest development in the middle grades is that students will begin to interpret maps and rock strata to identify significant features in Earth's history. Students will need to apply their understanding of tectonic processes and as well as interactions between earth's systems in order to associate features in rock layers with the events that give rise to these features.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard (Overlap with 8.ESS2.1)

8.ESS2.1 – Analyze and interpret data to support the assertion that rapid or gradual geographic changes lead to drastic population changes and extinction events.

ESS2.A: Earth Materials and Systems

Guiding Question:

How do Earth's major systems interact?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to describe the interactions between four of Earth's major systems: the geosphere, the atmosphere, the hydrosphere, and the biosphere.

CENTRAL IDEA(S)

Four major systems on Earth include the geosphere, the atmosphere, the hydrosphere, and the biosphere. The boundaries between these systems are defined by the materials that make them up. The geosphere consists of solid and molten rocks, soils, and sediments. The atmosphere is the gases extending from Earth's surface to space. The hydrosphere includes all phases of water regardless of location. The biosphere includes living things in all spheres. The flow of matter and energy between and within these systems cause changes.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This component idea begins with students looking at how wind and water can create landforms that are used by living things. By late elementary students can define the specific systems noted in this component idea. In middle school students examine how interactions between the systems exist at a variety of scales of size and time – the microscopic transfer of elements and varying durations required for the processes that facilitate the transfer of matter and energy.

K-2 Standards

By the end of grade 2. Wind and water can change the shape of the land. The resulting landforms, together with the materials on the land, provide homes for living things. – NRC, 2012

Progression Across Grade Bands

Students have concrete experiences with wind and water. They can feel wind and water which helps them understand the way that pushes and pulls (PS2.B) from wind and water can change the shape of the land. These are interactions between the atmosphere/hydrosphere and the geosphere. These changes in the geosphere create opportunities within the biosphere for the living things depend on the land (LS2.A). One example of these system interactions are the caves carved by water that humans and other animals may use for shelter. The goal for this age is for students to see that systems connect, but students are not responsible for naming the systems or defining boundaries between the system.

The ideas of invisible forms of matter and unseen internal structures in later grades students will be prepared to think about the things organisms obtain from other systems (e.g., CO2 from the atmosphere, nutrients from the soil) as well as less visible systems, such as the atmosphere or Earth's interior.

By middle school students will have a more explicit understanding of the materials of each system and be prepared to consider how flows of matter and energy cause changes at different scales.

Current (2018 Implementation): 2.ESS2.2

2.ESS2.2 – Observe and analyze how blowing wind and flowing water can move Earth materials (soil, rocks) from one place to another, changing the shape of a landform and affecting the habitats of living things.

<u>Big Idea(s):</u>

Earth's systems are connected. One system (the atmosphere/hydrosphere) can change another system (geosphere) and the effects spread to other systems (biosphere).

<u>Scientific Ideas:</u>

- The Earth contains a variety of connected systems. [note: students are not expected to know the different systems, they are below here for clarity.]
- Wind (atmosphere) and water (hydrosphere) can move rocks and soil and change the shape of the land. (geosphere).

- The changes wind and water make to the land create landforms (e.g., caves, ponds, rockpiles).
- Living things (biosphere) depend on their surroundings to provide the things they need – including shelter.
- Living things use the landforms created by wind and water for shelter and use materials that become accessible because of the effects of water on other systems.

Example(s) of Common Student Ideas:

- The surface of the Earth does not change.

Revised (2025 Implementation): 2.ESS2.2

2.ESS2.2 – Observe and analyze how blowing wind and flowing water can move Earth materials (soil, rocks) from one place to another, changing the shape of a landform and affecting the habitats of living things.

3-5 Standards

By the end of grade 5. Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth's surface materials and processes. The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather. Rainfall helps shape the land and affects the types of living things found in a region. Water, ice, wind, living organisms, and gravity break rocks, soils, and sediments into smaller particles and move them around. Human activities affect Earth's systems and their interactions at its surface. -NRC, 2012

Progression Across Grade Bands

Students have seen that there are connections between different Earth systems even though the systems do not appear connected – wind and water, reshape the land which provides habitat for living things.

The major themes of system organization and internal structure drive the learning for this grade band. Earth is a big system made of smaller systems that include the geosphere, hydrosphere, atmosphere, and biosphere. Students see that living things as well as processes involving the freezing and thawing of water can break apart and move around rocks. Additional connections, such as the ocean as habitat and rainfall (hydrosphere) impacting the distribution of different types of living things (biosphere) are relevant to this component idea, though not called out in the standards.

By middle school students will have a more explicit understanding of the materials of each system and be prepared to consider how flows of matter and energy cause changes at different scales.

Current (2018 Implementation): 4.ESS2.1, 4.ESS2.4

4.ESS2.1 – Collect and analyze data from observations to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering (frost wedging, abrasion, tree root wedging) and are transported by water, ice, wind, gravity, and vegetation.

<u>Big Idea(s):</u>

Rocks may appear unchanging because changes may occur slowly or be so small that we may not be able to see them. Changes to the shape of the land (geosphere) can be caused by other systems.

[note: 4.ESS1.1 and 4.ESS2.1 both center on the idea that wind and water reshape Earth's surface. However, this bigger idea serves a different purpose under each standard. 4.ESS1.1 intends for students to understand that these processes are very gradual and large-scale effects of these processes that create landforms occur over extremely long spans of time. 4.ESS2.1 intends for students to see that interactions with other systems cause changes to Earth's surface and that the landforms, in turn, have effects on other systems.

Scientific Ideas:

- There are multiple systems that interact on Earth – the biosphere, the geosphere, the hydrosphere, and the atmosphere.
- Changes in one system also create changes in the other systems as energy transfers.
- Mechanical weathering refers to different processes where physical forces break rocks into smaller pieces due to interactions between the geosphere and other large systems, and/or interactions within the geosphere itself.
- Earth's surface includes landforms that are made of combinations of rock and soil (bits of rock combined with the remains of living organisms).
- Collisions between moving pieces of rock and sand can cause them to break into smaller pieces.
- Water that falls onto Earth's surface may move into cracks between rocks, into the soil, or flow across Earth's surface.
- Flowing water and wind can transport bits of rocks from places where they were broken.
- Water that flows across Earth's surface will flow downhill or accumulate in places where its path is blocked.
- Bits of rock will accumulate at various places when the forces that move them are no longer strong enough to push them further.
- Gravity explains the tendency of materials to sometimes fall or move downhill (e.g., gravity explains why water ends up in the ocean and takes materials with it). *[note: Gravity is not treated as a force (PS2) until 5th grade and students may not think of gravity as pushing or pulling on the objects.]*
- Moving water can cause rocks to collide which breaks them into smaller pieces, as well as transport the rocks as it flows.

Example(s) of Common Student Ideas:

- Rocks can only break when they fall and smash onto the ground.

4.ESS2.4 – Analyze and interpret data on the four layers of the Earth, including thickness, composition, and physical states of these layers.

Big Idea(s):

Students develop and understanding that the Earth's geosphere includes both the rocks and materials on Earth's surface as well as layers inside of the Earth that each have a unique composition.

Scientific Ideas:

- Earth's systems include the atmosphere, hydrosphere, biosphere, and geosphere.
- This standard elaborates on the internal structure of the geosphere to include: the crust, mantle, outer core, and inner core.
    - Knowing the characteristics of each layer prepares students to understand processes in a higher grade, such as convection within the mantle or radioactive decay within Earth's core.
    - Understanding of the relative positions, thicknesses, and compositions of these layers.
- The geosphere of Earth is divided into four layers (from surface to interior): Crust, Mantle, Outer core, Inner core.
- Knowing the composition of the layers in fourth grade is confined to just knowing whether the layer is liquid or solid and whether the layer is mostly rocky or mostly metal.
    - Crust = solid, mostly rocky
    - Mantle = semi-solid, mostly rocky
    - Outer core = liquid, mostly metal
    - Inner core = solid, mostly metal
- "Thickness" refers to the width of each layer, as opposed to the density.
    - Crust: 50 km average thickness (varies based on whether the crust is oceanic or continental)
    - Mantle: about 2,840 km thick
    - Outer Core: about 2,260 km thick
    - Inner Core: about 1,220 km thick

Example(s) of Common Student Ideas:

- The Earth's interior is made of dirt.

Revised (2025 Implementation): 3.ESS2.1, 4.ESS2.1

3.ESS2.1 – Develop a model to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

4.ESS.1 – Collect and analyze data from observations to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering (e.g., frost wedging, abrasion, tree root wedging) and are transported by water, ice, wind, gravity, and vegetation.

6-8 Standards

By the end of grade 8. All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms. The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future. – NRC, 2012

Progression Across Grade Bands

In earlier grades, students developed an understanding that Earth's systems are inextricably connected. In the middle grades, students should come to understand that the cycling of energy and matter forms the ties between the systems. Middle grade examples of the cycling of energy and matter focus on the processes that happen in Earth's geosphere. An understanding of scale and specific elements and nutrients provide an opportunity for students to imperceptible connections between systems. Over long periods of time, the weathering of rocks releases nutrients used by plants. Plants die and the nutrients return to become part of the soils and potentially sediment.

Current (2018 Implementation): 8.ESS2.2, 8.ESS2.3

8.ESS2.2 – Evaluate data collected from seismographs to create a model of Earth's structure.

Big Idea(s):

- Bore holes are holes drilled in the Earth's surface and can be used to learn about the materials that make up the inside of the Earth. The deepest bore hole humans have completed does not even reach half-way through the Earth's crust. Scientists apply understanding of waves and data collected on seismograms to create models of the Earth's interior (a geosphere sub-system).

Scientific Ideas:

- Mechanical waves cause temporary displacement of the medium that they travel through.
- Some waves travel through a medium in one direction and form wave pulses that move up and down in the other direction (e.g., a wave on a string moves along the string, but the string is displaced up and down). Other waves travel through a medium in the same direction as their wave pulses (e.g., a wave pulse traveling down a coiled spring that has been "plucked").

- At times (such as following an earthquake) the surface of the earth can shake as waves pass by a point.
- Seismographs are tools that measure the intensity and timing of the movements in Earth's surface and create a recording of this information (a seismogram).
- Seismic disturbances create waves that travel in all directions from the point where the disturbance occurs.
- One type of wave (p-wave) is a compression-type wave that moves quickly through the Earth's surface. Since any material can experience compressive forces (you can push down on liquids and solids), this wave travels through all regions of the Earth.
- Another type of wave (s-wave) is a side-to-side wave. Since you cannot pull sideways on liquids, this type of wave cannot pass through liquids or parts of the earth that are liquid.
- P-waves travel more quickly than s-waves.
- Seismograms will show less movement from earlier arriving p-waves and more movement from later arriving s-waves.
- Seismograms further from the position of the initial disturbance will record less intense movement as the energy of the wave dissipates.
- The path of a wave changes (refracts) as it travels from one type of material to the next (e.g., moving from air to water, or water to oil).
- Models of the Earth's interior with a solid inner core, a liquid outer core, and a solid mantle and crust explain P wave shadow zones and S wave shadow zones that appear when comparing seismograms from multiple sites.
- The mantle is often characterized as a liquid, but the materials behave nearly as a solid with incredibly slow movements. Treating the mantle as a liquid does not support the observations of seismic wave data.

<u>Example(s) of Common Student Ideas:</u>

- Humans use samples taken from the different layers of Earth to figure out what each layer of the Earth is made of.

8.ESS2.3 – Describe the relationship between the processes and forces that create igneous, sedimentary, and metamorphic rocks.

<u>Big Idea(s):</u>

The different types of rocks found on Earth's crust are created by interactions between the geosphere and Earth's other systems. Understanding the processes that form each of these different rock types helps to understand Earth's history (link to ESS1.c).

<u>Scientific Ideas:</u>

- Igneous rocks form from melted rock materials from the Earth's mantle. This rock material moves into/through the Earth's crust and cools.
- The heat that melts igneous rocks comes from Earth's core.
- Sediment forms from broken down rock material that is transported by wind or water.
- Sedimentary rock typically forms slowly where water accumulates.
- Sedimentary rock forms from small bits of broken-down rock material that accumulates and becomes cemented (stuck) together.
- Sedimentary rock is evidence that water was once located at the location where it is found.
- Metamorphic rocks form from existing rocks (igneous, sedimentary, earlier metamorphic) after they experience very large amounts of heat and pressure.
- The pressure and heat compact the earlier rock types, making them more dense along with chemical changes.
- Metamorphic rocks form when there is not enough heat to melt the rock completely, otherwise igneous rocks would form. At times, metamorphic rocks form near igneous rocks where the heat from the igneous rock formation deforms the existing rocks.
- Metamorphic rocks are evidence of tectonic activity in a region at some point in that place's history.
- The heat and pressures needed to form metamorphic rocks occur deep within the Earth's surface or at plate boundaries.

Example(s) of Common Student Ideas:

- All igneous rocks come from volcanoes.

Revised (2025 Implementation): 8.ESS2.1

8.ESS2.1 – Analyze and interpret data to support the assertion that rapid or gradual geographic changes lead to drastic population changes and extinction events.

ESS2.B: Plate Tectonics and Large-Scale System Interactions

Guiding Question:

Why do the continents move, and what causes earthquakes and volcanoes?

The Biggest Ideas

PURPOSE

This component idea explores the geosphere and helps students understand past and current movements and changes to the rocks at Earth's surface and how the plate tectonic theory explains these changes.

CENTRAL IDEA(S)

Earth's geosphere changes as mountain ranges and ocean basins are created or destroyed and during associated events such as earthquakes and volcanoes. Tectonic theory explains that these changes occur due to movements of enormous portions of Earth's crust forced by convection within Earth's interior. The convection cells are fueled by energy released during the decay of radioactive materials in Earth's core.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

There are two strands within this component idea. The first component idea addresses the variety of materials (K-2) and landforms (3-5) found on Earth. This progression overlaps with a second progression about mapping and analyzing maps of Earth's features. In middle school these two strands merge as students explore the mechanism and evidence that support tectonic theory.

K-2 Standards

By the end of grade 2. *Rocks, soil, and sand are present in most areas where plants and animals live. There may also be rivers, streams, lakes, and ponds. Maps show where things are located. One can map the shapes and kinds of land and water in any area. – NRC, 2012*

Progression Across Grade Bands

As students explore maps in this grade band there are two major concepts to communicate. The first is that Earth's surface has different types of materials found there which include rocks, soils, and sand. Activities such as a soil analysis for a school garden can help students build awareness of different materials. The second is that maps can show where different materials can be found in an area.

In the earliest grades, students explore simple maps that consist primarily of shapes and labels. Creating or using maps provides a way for students to begin that Earth's surface has different types of materials – rocks, soils, and sand. For example, students can map the outline of a lake or field and label the types of material they find there – water and perhaps sand, soil, etc. Since discussions should be limited to concrete observations, it is not necessary for students to understand that lakes or the ocean have solid materials underneath them.

Maps are a good way to communicate the evidence that supports tectonic theory. Students who learn to read maps in the elementary grades are ready to understand evidence for tectonic theory that they will explore in later grades, such as the location of earthquakes that correspond with plate boundaries or the patterns in rocks that form at divergent plate boundaries along the ocean floor.

Current (2018 Implementation): 2.ESS2.3

2.ESS2.3 – Compare simple maps of different land areas to observe the shapes and kinds of land (rock, soil, sand) and water (river, stream, lake, pond).

Big Ideas:

Students can use maps to show the location of different types of Earth materials and features that they find around them.

Scientific Ideas:

- There are different types of materials on Earth's surface including:
  - Rocks including bedrock and pieces of rock that break off of the bedrock.
  - soil - bits of rock combined with the broken down remains of living organisms.

    - sand - finely broken-down bits of rocks (minerals). *[In these grades, students do not need to recognize the difference between rocks and minerals.]*
- These different types of materials often accumulate so that large amounts of the material are found in one place (e.g., beaches often contain large amounts of sand, fields and forests often contain large amounts of soil, cliffs and plateaus often contain large amounts of exposed rocks and bedrocks).
- Maps can show the locations where these materials accumulate.
- Outlines on maps show the boundaries and shapes of the areas where materials accumulate.
- Maps show differently shaped areas that may contain or be made of different materials.
- On a map, there are no gaps or spaces between different areas.
- Maps can show the shapes of different types of water bodies (e.g., lakes, streams, rivers, oceans). (*Note: In K-2, students focus on visible/external features, so elements such as lakebeds that are covered by water are not necessary on their maps.)*

Example(s) of Common Student Ideas:

- All "dirt" is the same.

Revised (2025 Implementation): 2.ESS2.3

2.ESS2.3 – Develop and compare simple maps of different land areas to observe the shapes and kinds of land (rock, soil, sand) and water (river, stream, lake, pond).

3-5 Standards

By the end of grade 5. *The locations of mountain ranges, deep ocean trenches, ocean floor structures, earthquakes, and volcanoes occur in patterns. Most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans. Major mountain chains form inside continents or near their edges. Maps can help locate the different land and water features where people live and in other areas of Earth. – NRC, 2012*

Progression Across Grade Bands

Students began this progression by learning that there are a variety of different materials (e.g., rocks, sand, soils, water) found on Earth's surface and that shapes on maps can outline boundaries where different types of materials are found.

Two different, though increasingly connected areas of focus continue within this component idea about the geosphere. When looking at maps students should progress from identifying the types of materials at a location to different types of landforms occurring on maps. Students can look for patterns across different maps. For example, students may notice that cave formations exist in some parts of Tennessee where the underlying materials are limestone, but not in parts of Tennessee where the underlying materials are sandstone. Such an observation requires data (maps) showing the location of caves and showing the different types of materials. The goal is not for students to be able to name a variety of landforms. Students should become competent in identifying patterns, which can lead them to developing explanations for an underlying cause for the patterns they find.

A second set of map-based observations continue to reveal observations explained by the plate tectonic theory. Earthquakes and volcanoes at the boundaries between continents and oceans and the location of mountain ranges will be explained in middle school by the events occurring at subduction zones.

Late elementary students should understand that bodies of water rest on top of solid materials. It is not necessary to distinguish between oceanic and continental crusts at this point. Differences in the rock types in oceanic and continental crust require students to understand density.

Current (2018 Implementation): 4.ESS2.2

4.ESS2.2 – Interpret maps to determine that the location of mountain ranges, deep ocean trenches, volcanoes, and earthquakes occur in patterns.

<u>Big Ideas:</u>

Maps can show the locations of features and events. Reading these maps allows scientists to uncover patterns in the relative locations of these features and events.

<u>Scientific Ideas:</u>

- The simplest maps of Earth's surface show the boundaries between land and water, including the boundaries between oceans and continents (boundary: students are not expected to name specific oceans or continents).
- Earth contains different types of features, in addition to the different types of surface materials explored in earlier grades.
- Maps can show that the locations where events have occurred in the past.
- It is possible to make maps that show features of the Earth that are covered by water.
- Many different features on Earth's surface occur on the interior of continents and oceans, not just at their edges.
- Mountain ranges and volcanoes are common features where oceans and continents meet. *[Note: discussion of plate boundaries is beyond the scope of this standard.]*
- Deep ocean trenches are located near coastlines.
- Coastal mountain chains and deep ocean trenches are found together near coastlines.
- The waves that people feel after an Earthquake all originate from one location (epicenter).
- Historical maps of earthquake locations can reveal patterns over time.
- Because earthquakes produce waves that travel away from their point of origin many people may feel shaking caused by the earthquake, giving the impression that the earthquake has a large geographic scale.

<u>Example(s) of Common Student Ideas:</u>

- Mountain ranges are permanent features on Earth's surface.

Revised (2025 Implementation): 4.ESS2.2

4.ESS2.2 – Explain how data from maps and other reliable sources can be used to determine patterns for the locations of mountain ranges, deep ocean trenches, volcanoes, and earthquakes.

6-8 Standards

By the end of grade 8. *Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geological history. Plate movements are responsible for most continental and ocean floor features and for the distribution of most rocks and minerals within Earth's crust. Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart. – NRC, 2012*

Progression Across Grade Bands

Earlier standards within this progression focus on reading maps with the purpose of understanding the variety of surface materials (K-2) and the patterns in the distribution of landforms on Earth (3-5).

In middle school students focus on understanding plate tectonics. Plate tectonic theory can explain many of the patterns that students observed in prior grades – location of mountain ranges, volcanoes, earthquakes, etc. The middle school standards about plate tectonics call for students to explore the mechanism that drives plate tectonics as well as a variety of pieces of evidence that support tectonic theory.

Current (2018 Implementation): 8.ESS2.4, 8.ESS2.5

8.ESS2.4 – Gather and evaluate evidence that energy from the Earth's interior drives convection cycles within the asthenosphere which creates changes within the lithosphere including plate movements, plate boundaries, and sea-floor spreading.

Big Idea(s):

Earth's plates are embedded in the upper mantle and move as part of an enormous convection cell that extends down to the inner mantle.

Scientific Ideas:

- The rock layer under Earth's surface is divided into massive sections of solid rocks called plates that are miles thick.
- The continents and ocean basins are part of the plates. The exposed solid rock of mountains is an example of plate material that is visible when it is not covered by water, soil, or loose rock such as sand.
- There are about 12-15 very large plates, each of which encompasses large areas of the earth's outer layer (e.g., an entire continent plus adjoining ocean floor, or a large part of an entire ocean basin). Together these very large plates make up most of the entire

outer layer of the earth. The rest of the outer layer is made up of some additional smaller plates.

- The boundaries of continents and oceans are not necessarily the same as the boundaries of plates. Some boundaries between plates are found on continents, some on ocean floors, and some in places where oceans and continents meet.
- Rocks can be solid, liquid, or in a slightly softened form.
- The layer beneath earth's plates is made of rock that is hotter and less rigid than the plates.
- The layer beneath earth's plates is just slightly softened (just as wax and metal become softened when heated but not yet melted).
- The layer beneath earth's plates moves very slowly and in different directions in different locations around the earth.
- While new plate material is being added as plates pull apart, other plate material is being folded upward or recycled into the interior of the earth so that the plate material that is lost in one place is balanced by the new plate material that is gained in another.
- Radioactive decay of materials within Earth's interior releases energy as heat.
- The heat from Earth's core softens the materials near the core and decreases their density which causes them to float upwards.
- Softened rock loses heat as it travels towards Earth's surface which causes it to become denser.
- The cooled material at the top of the lithosphere is denser and sinks back down towards Earth's core.

<u>Example(s) of Common Student Ideas:</u>

- Earth's plates are located deep within the Earth and are not exposed at its surface.
- Earth's plates are separated by empty gaps.
- There is one continent on each plate.
- The boundaries of continents are the same as the boundaries of plates.
- Continents sit on top of a layer of water and the plates are under that water.
- Plates are separated from each other by oceans.
- Continents are next to plates, but not part of plates.
- Rocks are always solid.
- The layer beneath Earth's plates is mostly solid rock/liquid rock/combination of solid & liquid.

8.ESS2.5 – Construct a scientific explanation using data that explains the gradual processes of plate tectonics accounting for A) the distribution of fossils on different continents, B) the occurrence of earthquakes, C) continental and ocean floor features (including mountains, volcanoes, faults, trenches).

Big Idea(s):

Plate tectonic theory provides a single explanation that accounts for a variety of Earth's features and events in its history.

Scientific Ideas:

- When two plates pull apart from each other, melted rock rises up between the plates. This rock solidifies as it cools, adding new oceanic plate material to the edges of both plates so that the plates are always in contact with each other and no space forms between them.
- The process of melted rock rising between the plates can be gradual, with the melted rock material slowly welling up between the plates, and it can be sudden, with melted rock material suddenly projecting out from between the plates in volcanic eruptions.
- Melted rock can well up or erupt anywhere along the boundary where two plates are pulling apart. As the melted rock cools, it begins to form a row of mountains along the edges of both plates where they are pulling apart.
- When two plates move apart and split a continent in two, an ocean basin forms between them that widens over time. The ocean basin grows as new plate material is continuously added to the edge of the separating plates.
- The earth's plates move continuously and very slowly (several inches per year) along with the slightly softened layer of rock beneath them.
- The motion of the plates results in the motion of all things that are part of the plates (e.g., continents, ocean basins, mountain ranges) and all things that sit on top of the plates (e.g., soil, ocean sediment, living things, and buildings).
- Because the slow motion of plates is continuous, it can result in plates moving great distances across the surface of the earth over very long periods of time.
- The direction of motion is different for different plates, and the direction of motion of a plate can change over time so that where a plate once pushed into another plate, it can later pull away from that plate.
- Because different plates move in different directions, plates can press together, move away from each other, and move alongside (parallel to) each other.
- It is possible to measure the rate of motion and direction of motion of a plate.
- Continental plate material makes up continents, oceanic plate material makes up ocean basins, and the top part of any plate can be made of either oceanic or continental plate material or continental plate material in some places and oceanic plate material in other places.
- Continental plate material is made of rock that is less dense and much thicker than oceanic plate material.
- When two plates press together, if one plate has plate material at its edge that is less dense than the edge of the other plate, the less dense plate material will crumple upward, creating a bend or fold in the plate material but not causing the plate to break

into smaller pieces of rock. If the plate material is approximately the same density on both edges, the edges of both will crumple upward.

- When continental plate material from one plate presses against oceanic plate material from another plate, the continental plate material crumples up over the oceanic plate material.
- As continental plate material from one plate presses against continental plate material from another plate, the edges of both plates crumple up, creating a bend or fold in the plate material but not causing the plate to break into smaller pieces of rock.
- The result of a plate crumpling up is mountains, which are composed of the continental plate material that has been folded upward.
- The crumpling up of plate material reduces the area of the earth's surface covered by a plate.
- New mountains have formed throughout earth's history, and mountains continue to develop as plates move and press together.

Example(s) of Common Student Ideas:

- Mid ocean ridges form where two oceanic plates run into each other.
- There is no difference between oceanic and continental crusts.

Revised (2025 Implementation): 8.ESS2.2, 8.ESS2.3, 8.ESS2.4

8.ESS2.2 – Evaluate data collected from seismographs to create a model of Earth's structure and to understand how energy is derived from Earth's hot interior.

8.ESS2.3 – Gather and evaluate evidence that energy from the earth's interior drives convection cycles within the asthenosphere which creates changes within the lithosphere including plate movements, plate boundaries, and seafloor spreading.

8.ESS2.4 – Construct a scientific explanation using data that explains the gradual process of plate tectonics accounting for (a) the distribution of fossils on different continents, and (b) continental and ocean floor features (i.e., mountains, volcanoes, faults, and trenches).

ESS2.C: The Roles of Water in Earth's Surface Processes

Guiding Question:

How do the properties and movements of water shape Earth's surface and affect its systems?

The Biggest Ideas

PURPOSE

This component idea explores the hydrosphere and the unique features of our planet that exist because water can be found as a solid, liquid, and gas on Earth.

CENTRAL IDEA(S)

The conditions of Earth allow water to exist as a solid, a liquid, or a gas. This ability is unique to water. Unlike other substances, changes in temperature are the only thing needed to move water between the land, oceans, and atmosphere. As it moves between these spheres and is used by living things, water reshapes Earth's surface. Water is the only substance that naturally exists as a solid, liquid, and gas on Earth.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression of standards partially answers the core question for ESS2 - "How and why is Earth constantly changing?" This grouping of standards focuses on the hydrosphere. The progression begins with students observing the different places and associated forms where we find water on Earth. Water vapor and groundwater sources emerge in late elementary school after introducing students to unseen forms of matter. Once students understand the various phases of water, they are able to consider how water moves between the land, ocean, and atmosphere. Middle school discussions of energy transfer and density as a property of allow students to consider water currents beneath the ocean.

K-2 Standards

By the end of grade 2. *Water is found in the ocean, rivers, lakes, and ponds. Water exists as solid ice and in liquid form. It carries soil and rocks from one place to another and determines the variety of life forms that can live in a particular location. – NRC, 2012*

Progression Across Grade Bands

Students begin to understand how water influences Earth by exploring basic features of water. This includes places where water is stored on earth as well as the idea that water can take different forms. Students learn that plants must have water and that some places can be too dry for living things to survive.

Students will discuss water vapor and evaporation in later grades after they learn about matter, including that it exists in forms we cannot see.

Current (2018 Implementation): 2.ESS2.4

2.ESS2.4 – Use information obtained from reliable sources to explain that water is found in the ocean, rivers, streams, and ponds, and may be solid or liquid.

Big Ideas:

Water is found and moves between places on Earth. The water in these different places can freeze and thaw.

Scientific Ideas:

- Water is found at different places on earth – filling ponds, rivers, and streams.
- There are some places on Earth where water appears to sit.
- There are some places on Earth where water moves across the ground.
- The places where water appear to sit (ponds, lakes, the ocean) are often connected by sections of moving water (rivers and streams).
- Moving water tends to follow the same path – rivers & streams usually stay within their banks. Even a spring that is not constantly flowing will follow the same path whenever water returns.
- When it is cold enough water can freeze and become solid.
- Solid water will become liquid water again when it is warm enough.
- In some places, the portions or an entire body of water freeze and become solid.
- A frozen body of water still contains water and will become a liquid again when the temperatures rise.

Example(s) of Common Student Ideas:

- When a stream or pond freezes, the solid surface is not water.

Revised (2025 Implementation): 2.ESS.4

2.ESS2.4 – Use information obtained from reliable sources to explain that water is found in the ocean, rivers, streams, lakes, and ponds, and may be solid or liquid.

3-5 Standards

By the end of grade 5. *Water is found almost everywhere on Earth: as vapor; as fog or clouds in the atmosphere; as rain or snow falling from clouds; as ice, snow, and running water on land and in the ocean; and as groundwater beneath the surface. The downhill movement of water as it flows to the ocean shapes the appearance of the land. Nearly all of Earth's available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere. – NRC, 2012*

Progression Across Grade Bands

Physical science standards in third grade allow students to uncover that matter can exist even when we cannot see it – such as gases or even dust. This allows students to consider that water is also to exist in forms that are not visible. In earlier grades students explored places where familiar liquid forms of water are found. Now students build upon their physical science understanding to explore the less visible or familiar stores for water on Earth.

Current (2018 Implementation): 3.ESS2.1

3.ESS2.1 - Explain the cycle of water on Earth.

Big Ideas:

Water's chemical properties allow it to exist as a solid, a liquid, and a gas on Earth. As water changes phases it moves through Earth's systems and causes changes to Earth's surface.

Science Ideas:

- All forms of matter (solid, liquid, and gas) are made of collections of particles.
- Gases are invisible because the space between particles is so large (relative to the size of the particle).
- There are places on Earth that are cold enough for water to exist as a solid, but most of the temperatures on Earth cause water to exist in a liquid form. For this reason, most of the water on Earth is a liquid.
- In a liquid, particles are able to slide past each other. This property means that water will flow and run downhill across surfaces or into the ground.
- In a solid, particles cannot slide past each other, and so solid water (snow and ice) can accumulate in cold places.
- As a substance warms up, the particles in that substance move faster. This can lead to ice becoming liquid water or liquid water becoming water vapor.
- Water vapor is one of the gases in our atmosphere.

- As a substance cools down, the particles in that substance slow down. This can lead to liquid water becoming solid water, or water vapor becoming liquid water.
- Clouds and fog form when water particles begin to stick together and form tiny droplets of water.
- When enough water droplets collect in a cloud, they become too heavy and leave the atmosphere.
- Water flows downhill across the land and infiltrates the ground.
- Water accumulates in the oceans and large bodies of water, to a lesser extent.
- The Sun warms Earth's surface, including bodies of water. This can cause liquid water to enter the atmosphere as water vapor.
- Plant roots pull water from the soil, through the stem of the plant, and out to the leaves. By allowing water to escape from their leaves, plants maintain this upward movement of water from the soil. This process means that plants are continually moving water from the geosphere into the atmosphere.

Example(s) of Common Student Ideas:

- Clouds are made of water vapor.

Revised (2025 Implementation): 3.ESS2.2

3.ESS2.2 – Develop a model to describe the cycling of water through Earth's spheres driven by energy from the sun.

6-8 Standards

By the end of grade 8. *Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation as well as downhill flows on land. The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. Global movements of water and its changes in form are propelled by sunlight and gravity. Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents. Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations. – NRC, 2012*

Progression Across Grade Bands

Students should be familiar with the variety of forms that water can take. There may be a need to support student understanding of the invisible forms of water and the cycling of water between forms and stores.

In middle grades, students continue to explore how the physical properties of water allow it to have a significant influence on Earth's systems. Water absorbs energy from the sun and transfers this energy around the globe. This distribution of energy influences weather and climate at locations around the globe.

Current (2018 Implementation): 6.ESS2.1

6.ESS2.1 – Gather evidence to justify that oceanic convection currents are caused by the sun's transfer of heat energy and differences in salt concentration leading to global water movement.

Big Idea(s):

Water in the ocean moves in patterns that are caused by the physical properties of water including its ability to dissolve materials and store energy. The movement of water carries the energy stored in the water to different locations around the globe creating patterns in weather and climate.

Scientific Ideas:

- Water is made entirely of water molecules.
- Materials on earth have physical properties that are unique to them – density, ability to dissolve materials, ability to absorb heat, crystal structure.

- Water can dissolve a variety of different solid materials (minerals, rocks).
  - Pure water has the same density at all places on Earth, but when materials dissolve in a sample of water, it will become denser.
  - Water can absorb relatively large amounts of energy without changing temperature or phase compared to other liquids.
- The light from the Sun transfers energy from the Sun to the Earth.
- Because the Earth is a sphere and due to the orientation of the Earth's equator relative to the Sun, rays of light that hit the equator transfer more energy per unit of the Earth's surface than the indirect rays of light that hit the poles.
- Water can absorb and hold the energy that reaches the Earth from the Sun.
- There are patterns in the arrangement of particles in solids, liquids, and gases. (e.g., particles in solids vibrate, but do not change positions, particles in gas move quickly.)
- Adding energy (heating) to a material causes the particles comprising the material to move/vibrate more quickly. When a material loses energy, its particles move more slowly.
- Particles are attracted to each other to different degrees.
- When water freezes, the water particles link together in a pattern that "pushes" out salt particles that do not fit well into the water crystal pattern. This also causes salt crystals to form.
- The formation of ice sheets in the ocean will also cause salt to accumulate around areas where the ice sheets form.
- These salt crystals become part of the surrounding ocean and these areas of ocean become denser.
- The denser water creates downward currents at the poles where the ice sheets form. As the denser water sinks, surface water is pulled towards the pole to replace it.
- Land masses and underwater canyons influence the path of ocean currents in the deep ocean in the same way that they influence the paths of streams and rivers through canyons on land.
- Four main ocean basins create the "canyons" that the deep ocean currents flow through.
- The process of ice formation feeds water into the Atlantic Basin starting at the North Pole as descending water falls to the bottom of the Artic Ocean and spills out along the ocean floor into the Atlantic Basin.
- The topography of the ocean floor and rotation of the Earth generally confine this water in the Western Atlantic Basin.
- The deep, cold-water flows through the Atlantic Basin passing by the equator and down towards the Southern Ocean. The deep current is too far from the surface of the ocean to be warmed by the sun. This current flows towards Antarctica.
- The process of ice formation feeds water into three basins surrounding Antarctica – the Indian Ocean Basin, the Pacific Basin, and the Atlantic Basin.
- The current flowing into the Atlantic Basin from Antarctica collides with the front edge of the deep water that has traveled south from the North Pole. As these waters mix, the less dense portions of these waters flow upwards and surface in the Southern Ocean.

- The deep currents flow through the Indian and Pacific Basins towards the North Pole. These currents are pushed towards the surface as they run into land masses.
- Major surface and intermediate (not deep) currents flow towards the North Atlantic to replace the water that is drawn downwards into the Arctic Basin.

Example(s) of Common Student Ideas:

- The ocean floor is relatively flat.
- When water freezes, the salt becomes part of the ice.
- The water at the bottom of the ocean just sits there.

Revised (2025 Implementation): 6.ESS2.2, 6.ESS2.4

6.ESS2.2 – Gather evidence to justify that oceanic convection currents in a system are caused by the sun's transfer of thermal energy and differences in salinity leading to global water movement.

6.ESS2.4 – Develop and use a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.

ESS2.D: Weather and Climate

Guiding Question:

What regulates weather and climate?

The Biggest Ideas

PURPOSE

This component idea explores conditions in the atmosphere – the weather – as well as factors that interact to shape Earth's climate.

CENTRAL IDEA(S)

Weather is a description of the atmosphere at one time and place, while climate describes the weather over longer periods of time at that place. The weather and climate at a place are caused by interactions among multiple factors – sunlight, the ocean, the atmosphere, ice, landforms, and living things. As people learn more about how these factors contribute to the climate at a place it is possible to predict how changes to these factors can cause the climate to change.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression of standards partially answers the core question for ESS2 - "How and why is Earth constantly changing?" The ESS2.D standards focus on the atmosphere. Weather and climate are caused by the interactions between the atmosphere and Earth's other systems, including the transfer of matter (water, greenhouse gases, etc.) and energy in and out of the atmosphere. Weather changes frequently with respect to scales of both time and location, while changes in climate occur at larger scales.

K-2 Standards

Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region at a particular time. People measure these conditions to describe and record the weather and to notice patterns over time.

Progression Across Grade Bands

Weather is the condition of the atmosphere. In later grades, students learn that matter can exist in forms that we cannot see, that the atmosphere is made of a variety of invisible gases, and that the “weather” that they experience is caused by things happening with those invisible gases. Before students consider the atmosphere as a collection of invisible gases, they should begin to observe the different types of weather they experience firsthand and search for patterns in the sets of conditions.

Current (2018 Implementation): K.ESS2.1, K.ESS2.2

K.ESS2.1 – Analyze and interpret weather data (precipitation, wind, temperature, cloud cover) to describe weather patterns that occur over time (hourly, daily) using simple graphs, pictorial weather symbols, and tools (thermometer, rain gauge).

Big Ideas:

Descriptions of the weather should include more than one component. Descriptions that only include one component of the weather do not communicate the conditions completely. For example, 55 degrees and sunny will feel quite different from 55 degrees, cloudy and windy. Complete descriptions of the weather allow students to see how components change together. For example, when the sun is out, the temperature gets higher or that big changes in temperature often happen on windy days.

Scientific Ideas:

- Weather can change quickly and is a combination of factors.
- The direction and speed of air/wind can be measured.
- Air temperature can be different at different places.
- The appearance of the sky can be described. (In later grades these descriptions are analogous to visibility.)
- Light from the sun directly warms the things that make up the Earth.
- There are typical patterns for how the temperature changes over the course of a day and the course of a year.
- The patterns for the rise and fall of the temperature over the course of a day are due to variations in the amount of sunlight at a location.
- There are patterns for co-occurring conditions (e.g., it is cloudy when it rains, temperatures often drop after it rains, temperature changes are more significant on windy days).

- *Boundary: Station Models, or other models, are useful ways to represent weather. Students are not responsible for memorizing specific representations of data. However, using elements from these representations (e.g., sky coverage, wind direction) may help students organize their observations.*

Example(s) of Common Student Ideas:

- If it is raining in the morning, it will rain all day.
- It is always hot when it is sunny.

K.ESS2.2 – Develop and use models to predict weather and identify patterns in spring, summer, autumn, and winter.

Big Ideas:

There are patterns in the conditions of the weather from year to year that occur together and remain stable for longer spans of time. For example, there are times during the year where the temperatures are consistently lower than during other parts.

(Note: Focus on concrete experiences to guide student learning. Students are not expected to understand that some places around the world may not have all seasons nor that seasons happen during different months in the different hemispheres.)

Scientific Ideas:

- Temperature, wind, sunlight, clouds, rain, snow, fog are all elements of the weather that can be described.
- The seasons are defined by the weather conditions.
- The sun is out for different amounts of time each day.
- The number of daylight hours increases in the spring and decreases in the fall.
- Since the sun is out for less time each day in the winter, it warms Earth's surfaces less in the winter at a particular location and this is one cause for cooler temperatures when days are shorter.
- Patterns in conditions persist over time, with some variations in the middle of the patterns. (E.g., Temperatures will remain mild for weeks at a time, as opposed to swinging between extreme highs and extreme lows over short periods of time.)

Example(s) of Common Student Ideas:

- Seasons are defined by particular months.
- The sun is out for the same amount of time each day.

Revised (2025 Implementation): K.ESS2.1, K.ESS2.2, K.ESS2.3

K.ESS2.1 – Make observations to gather weather data (i.e. precipitation, wind, temperature, cloud cover) using tools (e.g. thermometer, rain gauge).

K.ESS2.2 – Use simple graphs and pictorial weather symbols to describe weather patterns that occur over time (i.e. hourly, daily).

K.ESS2.3 – Develop and use models to predict weather and identify patterns in spring, summer, autumn, and winter.

3-5 Standards

Weather is the minute-by-minute to day-by-day variation of the atmosphere's condition on a local scale. Scientists record the patterns of the weather across different times and areas so that they can make predictions about what kind of weather might happen next. Climate describes the ranges of an area's typical weather conditions and the extent to which those conditions vary over years to centuries.

Progression Across Grade Bands

In earlier grades, students learned to describe the various components of the weather. They also learned that some of these components change together. Students observed that weather changes are often gradual and that patterns exist over a day or a year, these patterns are repeated from one year to the next.

In upper elementary, students understand that descriptions of the weather reflect what happens at one location, at one moment in time and may be different at different locations. In contrast, climate describes the conditions of a location over longer periods of time. Climates may seem stable over years, but the climate at a location can change over longer periods of time – longer than a human lifetime, centuries.

Current (2018 Implementation): 3.ESS2.2, 3.ESS2.3, 3.ESS2.4

3.ESS2.2 – Associate major cloud types (cumulus, cumulonimbus, cirrus, stratus, nimbostratus) with weather conditions.

<u>Big Ideas:</u>

Clouds are accumulations of water droplets and ice. Conditions in the atmosphere determine the shape, motion, and distribution of clouds.

<u>Scientific Ideas:</u>

- Matter can exist even when it is so small that it is not visible.
- Water is a type of matter.
- The sky is not empty space. It is filled with a variety of gases, and we call this gas filled space the atmosphere.
- There is water vapor (a gas) in the atmosphere.
- The conditions in the atmosphere are not the same in all places, even at the same moment in time.
- The temperature of the atmosphere is lower the higher you go.
- Air near the surface of the Earth receives energy (is heated) by the energy released (cooling) of the Earth's surface.
- Air that has been warmed by the surface of the Earth will rise.

- The amount of water in the atmosphere is not constant – there can be pockets with more or less water present.
- Air can maintain its properties as it moves – such as the amount of water it contains and the temperature of the air.
- At any temperature, there is a maximum number of particles of water vapor (gaseous water) that can be in the air. As long as there is more water available, the number of vapor particles will continue to increase until this maximum is reached.
- When the air has reached the maximum number of water vapor particles that it can hold at a given temperature, then any more particles of water will combine with existing particles and begin to form tiny droplets.
- Warmer air can hold more particles of water vapor than cooler air.
- Clouds are made of water that has turned into tiny droplets that are small enough to remain in the air. The droplets that make up clouds are not heavy enough to fall to the ground.
- The temperature, movements of air, and amount of water in the atmosphere determine the shape and distribution of clouds in the sky.
- Weather conditions at the Earth's surface are a result of things that happen in the atmosphere (e.g., Sunny days occur when clouds do not form in the sky that block the sun. The cooler the atmosphere becomes, the more water droplets will condense making it more likely that droplets will collect together and become heavy enough to fall as rain.)

Example(s) of Common Student Ideas:

- The sky is empty space except when we can see things – clouds, birds, planes.
- The conditions in the atmosphere are uniform.

3.ESS2.3 – Use tables, graphs, and tools to describe precipitation, temperature, and wind (direction and speed) to determine local weather and climate.

Big Ideas:

Weather data includes a variety of measurements that describe conditions in the atmosphere. By analyzing collections of weather data taken over longer periods of time it is possible to describe the climate in a region.

Scientific Ideas:

- Descriptions of weather are small scale – they reflect what is happening at a given moment in time and at one location.
- Different locations may experience different weather conditions.
- Descriptions of weather and climate include the same sets of measurements and observations.

- Climate is the longer-term description of a region's weather.
- Changes to the climate of a region occur, but historically these changes have not been perceptible over a human lifetime.

Example(s) of Common Student Ideas:

- Weather and climate mean the same thing.

3.ESS2.4 – Incorporate weather data to describe major climates (polar, temperate, tropical) in different regions of the world.

Big Ideas:

There are patterns in the data used to describe climates. These patterns are the basis for naming several different climate zones that are found on Earth. Distance from the equator (latitude) influences the amount of direct sunlight that a location receives and is the main cause of the distribution of global polar, temperate, and tropical zones across the globe.

Boundary: Convection is explored in middle school. Students are not responsible for explaining why temperate zones typically occur at 30 and 60 degree latitudes.

Scientific Ideas:

- Patterns in rainfall and temperature over many years are the primary factors that determine the climate at a place.
- Climate zones are areas with similar temperature and precipitation.
- The climate zones generally occur in bands that circle the globe, parallel to the equator.
- Climate at a location on Earth depends on interactions between the Earth's surface and the atmosphere. These interactions are influenced by both the latitude and geography at a location.
- Sunlight warms the surface of the air, water, land and other materials on Earth's surface.
- As the sun moves higher in the sky (directly overhead is the highest point) the angle that the sun strikes the Earth increases until it reaches a maximum of 90 degrees in some places where it is directly overhead.
- The Sun releases energy at a nearly constant rate. However, when the angle at which the sun strikes the Earth's surface changes, the amount of energy it transfers to the Earth's surface also changes. A location on Earth receives the most energy when the Sun shines directly overhead at that location.
- The smaller the angle of the sun in the sky (lower in the sky) the smaller the portion of the Sun's energy that reaches that place.
- Due to the fixed axis of rotation and the fixed plane of the Earth's orbit, there are places on the Earth's surface where the Sun will not shine directly overhead. *(Note: This standard does not expect students to learn that the tilt of the Earth's axis causes the Sun to be directly overhead at different latitudes between the tropics over the course of the year.)*

- Areas on Earth that have lower latitudes receive more energy from the sun and will have generally warmer climates. Areas near the poles receive less energy from the sun and generally have cooler climates.

Example(s) of Common Student Ideas:

- The different climates are defined by the types of organisms that live there.

Revised (2025 Implementation): 3.ESS2.3, 3.ESS2.4

3.ESS2.3 – Use tables, graphs, and tools to describe precipitation, temperature, clouds, and wind (i.e., direction and speed) to predict local weather and climate.

3.ESS2.4 – Incorporate weather data to describe major climates (e.g., polar, temperate, tropical) in different regions of the world.

6-8 Standards

Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. Because these patterns are so complex, weather can be predicted only probabilistically.

The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents. Greenhouse gases in the atmosphere absorb and retain the energy radiated from land and ocean surfaces, thereby regulating Earth's average surface temperature and keeping it habitable.

Progression Across Grade Bands

The progression continues to answer the question, "What regulates weather and climate?" Students have come to understand that the spherical shape of the Earth causes differences in the amount of energy transferred from the Sun. These differences create patterns in weather and climate zones based on latitude. The weather is a description of momentary conditions of the atmosphere, while climate describes the weather of a region over a longer period.

In middle grades students begin to look at the way that local geography and bodies of water influence climate and creates climates that are different than models that only include latitude-based climate zones.

Current (2018 Implementation): 6.ESS2.2, 6.ESS2.3, 6.ESS2.5, 6.ESS2.6

6.ESS2.2 – Diagram convection patterns that flow due to uneven heating of the Earth.

<u>Big Idea(s):</u>

The difference in energy input at the equator compared to the poles generates patterns in the large-scale movements of the atmosphere.

Boundary: A model for atmospheric circulation that includes three atmospheric cells per hemisphere is beyond the scope of this standard but is explored in 6.ESS2.3.

<u>Scientific Ideas:</u>

<u>Cause of uneven heating of the Earth.</u>

- The Sun's energy is the most intense when the sun shines directly overhead at a location. When the sun is at an angle, the light –energy transferred– is less intense.
- The angle of the Sun is closest to overhead, and at times directly overhead, at latitudes near the equator. As a result, locations near these latitudes can experience the most intense sunlight at certain times of the year.

- The Sun is never directly overhead at latitudes further from the equator and therefore these locations receive less energy over the course of a year.
- The equator receives the greatest amount of direct light (energy) from the Sun. Relative to surrounding latitudes, air at the equator will be warmer and will rise. The poles receive the least energy since direct rays do not strike the poles causing air at the poles to descend.

<u>Cause of convection cycles.</u>

- Earth's atmosphere is a fluid – a gas.
- The temperature of Earth's surface increases because of energy transferred from the Sun that reaches Earth's surface *as well as energy released within its interior*. (Boundary – radiation from Earth's core is beyond the scope of this standard.)
- The atmosphere warms up because the part of the atmosphere that is closest to the Earth absorbs heat that is released from Earth's surfaces (land and water).
- When part of a fluid (e.g., air or water) is warmer than the fluid around it, it rises. If it is cooler than the fluid around it, it falls. Once warmed, the gases at the lower portion of the atmosphere begin to rise, moving away from Earth's surface.
- When the fluid that is moving up or down runs into something, it will flow horizontally across that surface.
- Convection patterns are a combination of warm air rising, cool air sinking, and the horizontal movements caused by running into a boundary.
- As the upward moving gases rise through cooler portions of the atmosphere, they transfer energy to the cooler parts of the atmosphere. This causes the rising gases to gradually cool down as they continually lose energy to the surrounding atmosphere.
- When part of a fluid is cooler than the fluid it will sink. Therefore, cooled air descends towards the surface.
- As cooler portions of a fluid move through warmer areas, energy flows into the cooler fluid, causing the temperature of the surrounding warmer areas to decrease. Therefore, air that sinks onto Earth's surface absorbs energy from Earth's surface, lowering the temperature at these locations.

<u>Surface wind patterns that result from convection cycles.</u>

- Relatively warmer air rises at the equator and creates an area of low pressure.
- When a fluid that is rising or falling runs into something, it will spread out horizontally across the surface.
- The upper levels of the atmosphere act as a boundary and cause the rising air to spread towards the poles. Air that travels from the equator towards the poles also transfers energy from the equator towards the poles.
- Relatively cooler air at the poles falls and creates an area of high pressure. The Earth's surface acts as a boundary that causes this falling air to spread horizontally.
- Air (wind) moves across Earth's surface – from the poles towards the equator – because of the difference in pressures between the high pressure at the poles and low pressure at the equator.

Example(s) of Common Student Ideas:

- Most of the thermal energy in the atmosphere is caused by the Sun shining on the atmosphere.
- The equator receives the most direct sunlight because it is closer to the sun than the poles.

6.ESS2.3 – Construct an explanation for how atmospheric flow, geographic features, and ocean currents affect the climate of a region through heat transfer.

Big Idea(s):

There are broad patterns in the distribution of polar, temperate, and tropical climates around the globe. A collection of more specific factors cause the climate at a location, which may be different from predictions driven by large-scale models.

Scientific Ideas:

Broad Climate Models (Coriolis and atmospheric flows)

- The Earth rotates faster at its equator than it does at its poles.
  - The Earth rotates on an axis that is perpendicular to its equator.
  - As the Earth rotates, all locations on Earth follow circular paths each day that correspond with lines of latitude.
  - Circular paths near the equator have a larger diameter than locations near the poles. Locations near the equator travel further each day.
  - All locations complete their movements around a circular path in a 24-hour period – one day.
  - Latitudes near the equator rotate faster than latitudes near the poles since they travel a greater distance in a 24-hour period.
- Due to the differences in speed at different lines of latitude, the path of objects (including air masses) curves when they move in the direction of either pole (6.ESS2.2).
- The Coriolis effect explains climates affected by atmospheric phenomena such as the Trade Winds and ocean currents such as the Gulf Stream.
- The Coriolis effect explains the distribution of climate zones at 30 and 60 degree latitudes and an improved model of the movement of air in the atmosphere that includes three cells per hemisphere.

Effect of Ocean on local climate (heat transfer via ocean currents)

- Earth's surfaces and materials absorb energy from the Sun's light.
- Some materials heat up (absorb energy) and cool down (release energy) quickly, other materials heat up slowly and cool down slowly.
- Water heats and cools slowly which means that it is able to store energy.

- As ocean currents move water from one place to another around Earth, the currents also transfer the energy contained in that water which can heat/cool areas near the ocean.

Effect of Geographic features on local climate (transport of water vapor, cooling air/precipitation over mountains)

- Water transfer by the atmosphere
  - Liquid at the surface of the Earth (rivers, streams, lakes, oceans, from living things) can become a gas and when this happens the water vapor becomes part of the air in the atmosphere.
  - Because water from the surface can become water vapor, the air that is near water on the Earth's surface will usually contain more water vapor particles than air that is further away.
  - Moving air masses contain water vapor and can transport the water vapor to areas that are further away from bodies of water.
  - Air masses that absorb water while they are near a source of water are able to carry that water over land to areas that may not have a source of water nearby.
- Land-water interactions
  - Materials absorb and release thermal energy at different rates. The temperature of Earth's land surfaces changes more easily than its bodies of water when heated or cooled.
  - Two locations that receive similar inputs of solar energy because they have similar latitudes (e.g., San Francisco and St Louis) will have different patterns in average daily temperatures over the course of a year because large bodies of water absorb/release energy differently than land surfaces.
  - Characteristic properties (temperature and water vapor content) of an air mass can change as the air moves. (e.g., moving over a body of water is likely to cause the vapor content to increase, moving from warm areas to cool areas is likely to cause the temperature to decrease.)
  - Clouds and rain form as air cools and water vapor in the air cools to form water droplets.
  - At any temperature, there is a maximum amount of water vapor that the air can hold. As long as water is available, the humidity can increase until it reaches this maximum.
  - Warm air can hold more water than cooler air. As the temperature of the air increases it can hold more air.
  - Cool air holds can hold less water vapor than warm air. As air cools and the amount of water vapor it can hold decreases, excess water vapor will condense and form droplets causing rain.
  - The atmosphere stores energy in the motion of air particles. When there are more particles, and they are moving faster, there is more energy stored.
  - At higher elevations, there are less particles of air in a given volume.

- When a volume of air from lower elevations moves to higher elevations, the size of this volume of air will increase – because there is less weight from other particles in higher parts of the atmosphere pushing down on the volume.
- As the volume of air increases particles spread apart resulting in less energy per unit of volume and decreasing the water vapor that can be held in the volume of water.
- Wetter climates are more common on the faces of mountains nearer to a body of water where the humidity of the air increases as it moves across the water, then decreases as it moves over the mountain.

Example(s) of Common Student Ideas:

- The atmosphere is warmer at high elevations because it is closer to the sun.

6.ESS2.5 – Analyze and interpret data from weather conditions, weather maps, satellites, and radar to predict probable local weather patterns and conditions.

Big Idea(s):

It is possible to examine a collection of data to make predictions about the future weather. The quantity, type, and reliability of the data and the models used determine the accuracy of the prediction.

Scientific Ideas:

- Models are tools that we use to predict the weather, and everyone has some sort of model that they use to make their own predictions about the weather – when we see a sunny sky outside, we predict that it is not likely to rain in the immediate future.
- Humans have gotten better at forecasting the weather because the constant evolution of technologies (thermometers, computers to store and process data, remote weather stations, doppler, etc.) results in longer timespans of data, larger samples of data, and different types of data.
- Weather forecasters use models that incorporate weather related data to make projections about likely weather conditions.
- Forecasting models are revised and have improved over time because of improvements in weather data.
- Because weather models are based on historical data, changes to the climate of an area will affect the reliability of those models.
- Using the same set of data there can be different projections for the weather depending on which model a scientist/forecaster selects.
- Weather maps are a type of data representation.
- There are different types of weather maps that represent different components of the weather (temperature maps, rainfall totals, radar, etc.).

- Weather forecasting is probabilistic, not certain, because of the number of variables involved making accurate predictions.

Example(s) of Common Student Ideas:

- Weather forecasts are certain and if they end up being inaccurate compared to the actual conditions, it is because someone made a mistake.

6.ESS2.6 – Explain the relationship between the movement and interactions of air masses, high and low pressure systems, and frontal boundaries result in weather conditions and severe storms.

Big Idea(s):

The Earth's atmosphere is made of particles of air. A region of the atmosphere with consistent properties is called an air mass. Differences in pressure cause these air masses to travel across Earth's surface and the interactions between air masses cause our weather.

Scientific Ideas:

Air temperature causes pressure/density differences:

- The atmosphere is made of a variety of different types of gas. These gas particles are always moving and collisions between particles transfer energy between the particles causing slower moving particles to speed up and faster moving particles to slow down.
- The gases in the atmosphere have weight and are pulled by gravity towards the Earth's center. The weight of the column of air above a location pushes down on Earth's surface creating air pressure. The difference between high and low pressure in the atmosphere is due to the weight of these columns of air.
- Temperature and density are the primary factors that affect the weight of a column of air. Differences in these variables define the boundaries between adjacent air masses.
- Warm particles move faster than cold particles. The extra collisions between faster moving particles in warm air increases the distance between particles. As the particles spread out, there will be less in an area, so that volume of air weighs less (become less dense). Because there are less particles in a volume of warm air masses these masses exert lower pressure on Earth's surface.
- Since the particles in a cold air mass will be closer together there will be more particles of air in a given volume (more dense). Air masses are heavier when they contain more air particles. This means that the cooler air masses also exert more downward force (higher pressure) on Earth's surface.

- Water vapor is less dense than other gases in the atmosphere – there are less particles in a volume of air – so water vapor makes the air "lighter" and lowers the pressure of an air mass.

<u>Pressure differences cause winds and the movement of air masses:</u>

- Wind is a current of air particles.
- Volumes of cool air contain more particles than equal volumes of warmer air, so they are heavier (more dense) and will sink towards Earth's surface.
- Cool, dense, sinking air creates a region of high pressure at Earth's surface – lots of particles weighing down on the surface at that location. As particles accumulate, they push outwards from the point where they are accumulated. Air flows away from areas of high pressure.
- Less dense air rises. Warm air expands which means that its density decreases. The less dense air is pushed upwards, away from Earth's surface, by more dense air nearby. This lowers the pressure at the location where particles are being pushed upwards. Air flows towards areas of low pressure.
- When an area of high pressure is next to an area of low pressure, particles from the higher pressure area are pushed towards the lower pressure area creating a moving current of air particles. The moving current of particles pushes on objects and can cause them to move. We experience the air particles moving from high pressure areas into lower pressure areas as wind.

<u>Resulting weather conditions and severe storms.</u>

- Temperature is a measurement of how fast particles in a substance are moving. Higher temperatures indicate faster moving particles. Faster moving particles bounce off each other when they collide. Slower moving particles stick together.
- There is a limit to the amount of water vapor a volume of air can hold that depends on the temperature of the air. Warmer air can hold more water vapor than cooler air because particles in warm air have more energy (move faster) and so they are less likely to stick together when they collide.
- Once a volume of air has reached its maximum amount of water vapor, any extra water vapor that evaporates into this volume of air will condense (stick together) and make droplets. These droplets are liquid water and as they accumulate this creates weather phenomenon such as fog, clouds, or rain.
- If the particles in a volume of air slow down (cool), the air will no longer be able to hold as much water as vapor and particles will begin to stick together. Even if no new particles enter the volume of air, the existing water vapor will condense to form droplets due to the temperature decrease.
- When a warm air mass moves towards a cool air mass, the denser cool air mass will sink under the warm air mass. The cool air mass will lift the warm air mass upwards. If the

warm air is significantly less dense than the surrounding air it will accelerate upwards rapidly and may lead to thunderstorms.

- Depending on the temperature of the warm air mass and the amount of water vapor it contains, the mass will form clouds and the potential for rain and storms as it rises and cools.
- Severe weather is more likely when the properties of two air masses are less similar.

Example(s) of Common Student Ideas:

- Water vapor is liquid water in the air.
- Clouds are gas.
- The properties of air are the same everywhere on Earth.

Revised (2025 Implementation): 6.ESS2.3, 6.ESS2.6, 6.ESS2.7

6.ESS2.3 – Construct an explanation for how atmospheric flow, geographic features, and ocean currents affect the climate of a region through heat transfer.

6.ESS2.6 – Develop a model to explain the role of greenhouse gases in regulating the Earth's average surface temperature and keeping it habitable.

6.ESS2.7 – Collect data to provide evidence for how the interactions of air masses result in changes in local weather conditions and how that data can be used to predict probable local weather patterns.

ESS2.E: Biogeology

Guiding Question:

How do living organisms alter Earth's processes and structures?

The Biggest Ideas

PURPOSE

This component idea helps students understand that living things cause changes to Earth – including changes to Earth's surface and to the rates of naturally occurring processes.

CENTRAL IDEA(S)

Organisms change their surroundings as they attempt to obtain the things they need to survive. Plants, animals, microbes can cause changes that are observable and also changes that happen at scales that are too small to be seen. Some of the changes caused by living things are so gradual that the effects are only visible over geologic time scales. Living things can cause changes to the rates of natural processes.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression of standards partially answers the core question for ESS2 - "How and why is Earth constantly changing?" The ESS2.E standards focus on the biosphere – living organisms and how they impact the Earth.

This progression begins with students considering visible and local changes to the environment that are caused by living things. Later in elementary school students will consider changes at different scales, including the ways that organisms can affect larger regions or changes that occur at the microscopic level. Rate of change is a major concept in middle school. Students consider that changes can occur at geologic time scales and also that living things can accelerate changes that would occur at slower rates under typical conditions.

K-2 Standards

By the end of grade 2. Plants and animals (including humans) depend on the land, water, and air to live and grow. They in turn can change their environment (e.g., the shape of land, the flow of water). – NRC, 2012

Progression Across Grade Bands

In life science standards, students are learning that organisms have needs and that they meet these needs by getting things from their surroundings. The biogeology component idea (ESS2.E) helps students understand that organisms will change affect their surroundings as they go about meeting their needs. The main idea is that living things cause changes to the non-living environment.

Students should consider examples where the effects of the organisms are directly observable. For example, students may see tracks of dirt left in lawns where moles have tunneled in the dirt. Plants also change the environment. For example, tree roots, accumulations of leaves, and fallen logs may divert the flow of a stream. Humans are living things and change the environment in many ways. Students may see ruts where water runs off of roofs and across the ground or areas of compacted dirt on the playground near soccer goals, baseball bases, or other paths where people often walk.

In later grades, students will extend this understanding to the idea that changes accumulate over time and can occur in systems where they may not even be visible.

Note: Phenomena, such as the formation of most landforms, may not be a result of living organisms and form over very long periods of time. Such phenomena do not align to the intent of these standards.

Current (2018 Implementation): 2.ESS2.1

2.ESS2.1 – Compare the effectiveness of multiple solutions designed to slow or prevent wind or water from changing the shape of the land.

Big Ideas:

The Earth's surface changes naturally as its systems interact. Humans (as part of the biosphere) can do things that prevent the Earth's surface from changing.

(Note: In the K-2 grade band, students should focus on concrete examples. This means that examples used in early elementary should be limited to visible changes to the Earth's surface including the way water flows across its surface.)

Scientific Ideas:

- The surface of the Earth can change and looks different now than it did in the past.
- Wind and water can cause changes to the surface of the Earth.
- When the wind blows it can move things. On Earth's surface this can remove soils, especially light soils, and deposit these soils in new places.
- Surfaces can be worn down or broken apart as the wind blows bits of material across the surfaces.
- When water flows across the Earth's surface it can pick up materials and carry them to a different place and deposit them somewhere new.
- Material moving with the water can break apart the surface even more.
- Humans depend on their surroundings and changes to the surroundings may impact humans. When the changes are viewed as harmful, humans engineer solutions to prevent the changes.
- Depending on the problem, humans use a variety of solutions to keep the *wind* from moving soils. For example – plant cover can keep wind off a surface, water on the surface causes particles to stick together, tall plants and barriers can block the wind, limiting access to an area reduces traffic and limiting animal grazing which can allow plants to reestablish.
- Depending on the problem, humans use a variety of solutions to keep water from moving soils. For examples – surfaces may be covered by plants or rocks to anchor or cover soils, surfaces may be reshaped to control the direction water flows, structures may be built to control the flow/release of water, surfaces may be left in a natural state to allow water to enter soil.

Example(s) of Common Student Ideas:

- Earth's surface does not change.

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. Living things affect the physical characteristics of their regions (e.g., plants' roots hold soil in place, beaver shelters and human-built dams alter the flow of water, plants' respiration affects the air). Many types of rocks and minerals are formed from the remains of organisms or are altered by their activities. – NRC, 2012

Progression Across Grade Bands

In the earliest grades students considered ways that organisms can change their surroundings. Students should have encountered examples that were directly observable and local – e.g., on playgrounds.

This component idea progresses by considering changes at different scales. Examples of changes in earlier grades were directly observable – a compacted path of dirt or a stream that is blocked by a tree's roots. Students should consider some of these small, local changes impact larger regions. For example, water in streams can become cloudy with sediment if groundcover is removed from along the banks or when a tree falls and its root ball exposes, unanchored soil.

In students are also learning about a microscopic world of particles and microbes. This brings the opportunity to discuss the ways that microbes help recycle plant materials and create new soils. As students understand that air consists of particles of gas, including water vapor, students can understand how adding or removing plants can impact the atmosphere.

In later grades students will learn that all matter is made of a limited set of elements which allows students to consider things like the formation of fossil fuels over time, the release of stores of carbon, and specific gases that plants and animals exchange with the environment.

Current (2018 Implementation): 4.ESS2.3

4.ESS2.3 – Provide examples to support the claim that organisms affect the physical characteristics of their regions.

<u>Big Ideas:</u>

In their quest to survive, organisms make changes to the places they live that may also result in changes across larger areas.

<u>Scientific Ideas:</u>

- Organisms depend on their surroundings and behave in ways that make it more likely that they will survive.

- Actions organisms take that help them survive can cause changes to the places where they live.
- Changes made on a local scale can have consequences that cause additional changes at larger scales.
- The scale and significance of changes caused by organisms increases when populations grow in an area, or on Earth.
- An inexhaustive list of examples of changes caused by living organisms (the biosphere)
    - humans and beavers build dams that redirect the flow of water (hydrosphere)
    - plant roots can break apart rocks or prevent soil loss (geosphere)
    - burning wood and fossil fuels send small particles of smoke into the air (atmosphere)

Example(s) of Common Student Ideas:

- Only humans changes to Earth's surface.
- Only animals cause changes to Earth's surface.
- Only living things cause changes to Earth's surface.
- Living things are so small and the Earth is so big that living things cannot cause any significant changes to the Earth.

Revised (2025 Implementation): 4.ESS2.3

4.ESS2.3 – Provide examples to support the claim that organisms affect the physical characteristics of their regions (e.g., plants' roots hold soil in place, beaver shelters alter the flow of water, paved surfaces affect runoff, leaves from trees can obstruct waterways).

6-8 Standards

By the end of grade 8. Evolution is shaped by Earth's varying geological conditions. Sudden changes in conditions (e.g., meteor impacts, major volcanic eruptions) have caused mass extinctions, but these changes, as well as more gradual ones, have ultimately allowed other life forms to flourish. The evolution and proliferation of living things over geological time have in turn changed the rates of weathering and erosion of land surfaces, altered the composition of Earth's soils and atmosphere, and affected the distribution of water in the hydrosphere.
– NRC, 2012

Progression Across Grade Bands

In earlier grades students observed examples of humans and other organisms changing Earth's surface and systems. Some changes were readily observable, while other examples occurred at microscopic scales. The general emphasis has been on changes that were structural - e.g., changing the path of water, or the turbidity of a stream. "Rate" is the theme for this component idea in middle school – that changes can be gradual and that living things can accelerate natural processes.

Students should see the two-way connection between living things and Earth's structures and systems. In life sciences, students learn that organisms depend on their surroundings and cannot grow in places where their needs are not met. For example, plants only survive within certain ranges of light, precipitation, and temperatures. Sudden and cataclysmic events can create conditions where living things no longer survive even in places where they had previously thrived. These events create opportunities for new organisms to thrive.

The duality in this component idea comes in the way that these new organisms may create gradual changes to Earth's systems. Gradual changes occur over geologic time scales. For example, analysis of sedimentary rocks supports the claim that the Earth's present oxygen rich atmosphere is a result of photosynthesis by cyanobacteria. As oxygen became a more significant part of Earth's atmosphere, living things flourished and caused changes to the rate of change to Earth's surfaces.

Students have seen the ways that Earth's structures are changed by living things and can now address how living things also accelerate the rates of natural processes. For example, through composting humans can add organic materials to soils much faster than they would accumulate naturally.

Current (2018 Implementation): 6.ESS2.4, 8.ESS2.1

6.ESS2.4 – Apply scientific principles to design a method to analyze the impact of humans and other organisms on the hydrologic cycle.

Big Ideas:

Living things affect the hydrosphere. Some effects are directly observable, and others are not. The effects on the hydrosphere occur in a positive feedback loop.

Scientific Ideas:

- Water is found in a variety of forms and locations on Earth – as a liquid on and below Earth's surface in bodies of water and in aquifers, as a solid as ice in the ocean and snow, as a gaseous vapor in the air.
- Individual plants, animals and microbes take in water to survive.
- Water vapor is produced when living things release energy stored in carbon-based forms – breaking down food or burning fossil fuels.
- Greenhouse gases, including water, trap energy that would otherwise be radiated into space. By trapping this energy, the Earth maintains a relatively consistent temperature that has allowed life to flourish.
- Levels of greenhouse gases have increased during the industrial era of human history.
- As amounts of greenhouse gases in the atmosphere keep increasing the atmosphere warms.
- Warmer temperatures also reduce the size of ice sheets and surfaces that reflect incoming radiant energy. This causes even more warming as water absorbs energy from the sun.
- A warmer atmosphere holds more water vapor which can lead to heavier rains.
- Populations establish themselves in places where their needs are met. Over time technologies have been developed to divert and/or retrieve water to meet the needs of human populations.
- Technologies that allow humans to retrieve water from underground aquifers have allowed humans to access this store of water.
- Human civilizations have redirected the pathways of water for a variety of intentional and unintentional purposes – e.g., to supply water for agricultural purposes, to harvest potential energy of water flowing downhill, to redirect water to prevent flooding, paved surfaces that make travel safer.
- Redirecting the paths of water across Earth's surface can limit the amount of water that re-enters and recharges aquifers.

Example(s) of Common Student Ideas:

- All human impacts on the hydrologic cycle are negative.
- Living things are so small and the Earth is so big that living things cannot cause any significant changes to the Earth.

- Living things only affect the system they interact with directly. For example, burning fossil fuels adds carbon to the atmosphere, but this does not have an effect on the hydrosphere.

8.ESS2.1 – Analyze and interpret data to support the assertion that rapid or gradual geographic changes lead to drastic population changes and extinction events.

Big Ideas:

Living things require conditions within a range of tolerances. Major events in Earth's history led to conditions that were favorable for living organisms to thrive. At other times, events have created conditions that have led to extinctions.

(Note: The examples included below are not exhaustive. They represent examples of sudden or gradual events.)

Scientific Ideas:

- Conditions on Earth have changed.
- Changes to the Earth include changes that have been both gradual and sudden.
- Some changes have caused mass extinctions, but other changes have created the conditions that have allowed life to proliferate.
- Changes that occur rapidly are more likely to cause rapid decreases in population sizes, while changes that occur over generations provide an opportunity for species to adapt.
- Throughout Earth's history major changes to Earth's atmosphere have created conditions that resulted in major losses of species. There have been both biotic and abiotic causes for these periods of loss.
- In Earth's early history, photosynthetic organisms were not present to draw down levels of CO2. Methane (from Earth's interior and produced by sulfur consuming bacteria) and carbon dioxide present in Earth's early atmosphere kept the earth warm enough to keep oceans from freezing at a time when the sun released less energy.
- Photosynthetic cyanobacteria in the early ocean gradually increased oxygen levels allowing for an "explosion" in the number of organisms that could use this oxygen, but also causing the extinction of many organisms that had been successful on an oxygen-free Earth. Plants and bacteria have produced most of the oxygen in the atmosphere.
- Large volcanic events have reduced levels of sunlight and therefore plants' ability to produce oxygen.

Example(s) of Common Student Ideas:

- Conditions on Earth have not changed since its formation.
- All large-scale changes to the Earth have had negative consequences on living organisms.

Revised (2025 Implementation): 6.ESS2.5

6.ESS2.5 – Analyze and interpret data to determine the impact of humans and other organisms on the water cycle, landforms (e.g., rainshadow effect) and atmospheric systems.

ESS3.A: Natural Resources

Guiding Question:

How do humans depend on Earth's resources?

The Biggest Ideas

PURPOSE

The theme across all component ideas within the larger disciplinary core idea are the ways that Earth's processes affect humans and are, in turn, affected by humans.
This component idea explores the effects of Earth's natural resource availability on the development of human civilizations and then how civilizations, in turn, impact the availability of Earth's resources over time.

CENTRAL IDEA(S)

Humans depend on the environment to provide the materials they need. Civilizations develop in places where their needs are met. Growing populations and greater expectations for comfort and convenience have increased the types of quantities of natural resources used by humans. Scientific discoveries change the ways that humans meet their needs and their environmental impacts. There are no natural processes to break down some materials made by humans. These materials are effectively permanent and the atoms in these materials do not return to their natural cycles. As we understand more about Earth's systems our models offer better predictions about the effects of our decisions on the environment.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

Students begin this progression by exploring the ways some materials help living things indirectly meet their physical needs or provide comfort. In late elementary school students will learn that all the things that humans use and produce, including energy, can be traced back to natural sources and that the processes of obtaining and using the materials have effects on the environment. In middle school, students consider that some resources accumulate through geologic processes that take extremely long periods of time to develop.

K-2 Standards

By the end of grade 2. Living things need water, air, and resources from the land, and they try to live in places that have the things they need. Humans use natural resources for everything they do: for example, they use soil and water to grow food, wood to burn to provide heat or to build shelters, and materials such as iron or copper extracted from Earth to make cooking pans. – NRC, 2012

Progression Across Grade Bands

One idea for this progression is that human civilizations develop where natural resources are available. The concept of a civilization is beyond this grade band, so this progression begins by looking at individual organisms. There are related ideas in the life sciences that organisms can only live in places where their needs are met. These needs include air, food, water, and shelter. Humans use materials from their surroundings to meet their physical needs and make them comfortable. For example, humans depend on soil to provide food. Food meets physical need and healthy soil is a resource that humans depend on to meet their needs. Students should encounter examples of everyday objects created from materials sourced from their environment.

In later grades students will see that energy and many materials that humans use have been developed by humans by processing raw materials found on Earth (e.g., plastics, synthetic fibers in clothing).

Current (2018 Implementation): K.ESS3.1

K.ESS3.1 – Use a model to represent the relationship between the basic needs (shelter, food, water) of different plants and animals (including humans) and the places they live.

Big Ideas:

Organisms depend on the places they live in to meet their basic needs.

Scientific Ideas:

- Living things need certain things and conditions to survive – food, water, and shelter.
- Every basic material need that an organism has must be met by the place it lives.
- Living things try to live in places that meet their needs.
- Living things cannot live in places where their needs are not met.
- Different types of plants and animals have unique needs and habits. Different environments have different characteristics. Plants and animals live in places where their unique needs are compatible with the characteristics of their environment.

- The unique characteristics of each different environment will determine which plants and animals can live there.
- In places where landforms do not provide shelter, many types of animals use materials they collect to create shelter.

Example(s) of Common Student Ideas:

- The same materials are available everywhere around us.
- Immaterial things like shade are not important to living things.

Revised (2025 Implementation): K.ESS3.1

K.ESS3.1 – Use a model to represent the relationship between the basic needs (shelter, food, water) of different plants and animals (including humans) and the places they live.

3-5 Standards

By the end of grade 5. All materials, energy, and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not. – NRC, 2012

Progression Across Grade Bands

In earlier grades students explored the idea that some materials from an organism's environment can help organisms meet their physical needs. Some examples may have included using soil to produce food, using metals to produce different things around their homes, using wood to have fires to keep warm or for building. In physical science, students are learning about energy. Students are learning to associate energy with movement and with warmth. For example, living things use energy to move around.

This idea progresses as students learn that all the things around them and the energy they use to keep warm can be traced back to a natural source. Some material resources, such as cotton used for clothing, are derived from natural sources using simple processes. However other materials, such as synthetic fibers that may also be found in clothing, are man-made. Synthetic materials may have more complicated paths back to natural sources. The processes used to obtain raw materials from natural sources and to process materials during production of a finished good have effects on the environment. Materials that are more complicated to produce often remain in the environment for longer periods of time. For example, cotton is clothing breaks down and can even be composted. Other parts of clothing, such as elastic waistbands, will remain long after the cotton has decomposed.

As students learn to trace materials back to the natural sources used in their production, students will see that the availability of the raw materials can vary. Some raw materials can be produced in a way that is sustainable from year to year. Other raw materials form through processes that take longer periods of time to reproduce and can be depleted faster than they are restored. In later grades students will be able to connect the spread of civilizations to the availability of resources.

Current (2018 Implementation): 4.ESS3.1

4.ESS3.1 – Obtain and combine information to describe that energy and fuels are derived from natural resources and that some energy and fuel sources are renewable (sunlight, wind, water) and some are not (fossil fuels, minerals)

(Note: Differentiating between renewable and non-renewable based on how long it takes for the fuel to replenish is not the intent of this standard.)

<u>Big Ideas:</u>

All the energy that we use comes from some natural resource and there are different impacts for each type of energy.

Scientific Ideas:

- Humans depend on energy and use energy in a variety of ways – for cooking, transportation, comfort.
- There are a variety of different naturally occurring energy sources – mineral, fossil, wind, water, sunlight.
- All types of fuel and energy are derived from one of these resources that occurs naturally. *(Note: students should explore the ways that energy is derived from different natural resources but are not expected to memorize any of the processes.)*
- Some types of energy are captured and stored by humans (solar, wind, water). Other types of energy were originally stored through naturally occurring processes and are released by humans (fossil fuels, minerals, wood).
- There are positive and negative effects from using each type of energy.
- The use of any type of energy/fuel source has an impact on the environment. (E.g., Mines used to collect minerals result in habitat loss, dams used to generate power change waterways, burning fossil fuels creates air pollution.)
- Humans have developed technologies that allow them to capture energy from different sources including wind, water behind a dam, sunlight (renewable) and fossil fuels and minerals (non-renewable).
- Advancements in technology have and will reduce some of the negative effects of the different energy sources.

Example(s) of Common Student Ideas:

- Gasoline and other fuels are ready to use once they are extracted from the Earth.

Revised (2025 Implementation): 4.ESS3.1

4.ESS3.1 – Obtain and combine information to describe that energy, fuels, and materials are derived from natural resources and that some resources are renewable (e.g., sunlight, wind, water) and some are not (e.g., fossil fuels and minerals).

6-8 Standards

By the end of grade 8. Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geological processes (link to ESS2.B). Renewable energy resources, and the technologies to exploit them, are being rapidly developed. – NRC, 2012

Progression Across Grade Bands

Early grade standards focus on the idea that humans collect and refine natural resources as a way to provide materials and energy. All types of energy and all materials trace back to some type of natural resource and in early grades students examine the events that occur from the harvesting of the resource until its final form.

Middle grade students look back further in time to the processes responsible for the creation and distribution of the raw natural resources. When students understand the processes that form the natural resource, they have the context to differentiate between the resources that replenish quickly compared to resources that form over geologic time spans.

Ultimately, students should connect the way that human civilizations emerge to the distribution of natural resources. Trace amounts of most materials that humans use can be found across the planet, but it is not always practical to obtain these materials. It is more economical to attempt to extract materials where there are large accumulations of the material. These accumulations develop because of geologic processes. People, communities, and civilizations move into new areas or build new economies as humans develop new technologies to access resources or new technologies add value to resources that were not used previously.

Current (2018 Implementation): 6.ESS3.1, 6.ESS3.2, 8.ESS3.1

6.ESS3.1 – Differentiate between renewable and non-renewable resources by asking questions about their availability and sustainability.

Big Ideas:

The sources and raw materials underlying all types of material and energy production form through natural processes. These natural processes occur at different rates, and the rate of each process determines whether the resource is sustainable or could run out in time.

Scientific Ideas:

- All types of natural resources depend on natural processes to form. The processes that form the raw materials occur at different rates.

- Man-made/synthetic materials (artificial fibers, plastics, etc.) are derived from naturally forming materials.
- To determine whether a resource is renewable or not, it is essential to know the basic processes that accumulate the resource.
- The resources that accumulate through geologic processes require geologic time scales to form.
- Since human lifespans are so short compared to geologic timescales, the resources that form from geologic processes get used up faster than then are replenished.
- Non-renewable resources become less available over time because they are used up faster than they are able to be replenished.
- The sustainability of a material considers both the rates that the material is produced and the rate at which it breaks down.
- Sustainable materials form/replenish at faster rates than they are used. They also break down and return to natural systems at faster rates than they are created.

Example(s) of Common Student Ideas:

- All natural resources come from the land, but not from the air or waters.

6.ESS3.2 – Investigate and compare existing and developing technologies that utilize renewable and alternative energy resources.

Big Ideas:

Advances in technology allow humans to access different resource pools, to refine the resources more efficiently, and to decrease the negative effects of energy capture and use.

Scientific Ideas:

- All materials and types of energy used by humans trace back to some natural resources.
- Advances in technology have allowed humans to use new types of resources.
- Humans have also been able to use existing resources in new ways; e.g., human use of solar energy has advanced from passive heating to solar electric panels.
- Advances in technology have allowed humans to use resources more efficiently; e.g., as light-emitting diode (LED) light production has become less expensive, and the spectrum has increased, LEDs have become energy-saving alternatives to incandescent and fluorescent lights.
- As processes that refine raw materials and form them to finished goods improve it is possible to produce devices/components that were not possible previously; E.g., improved processes for refining cast iron have improved its quality and suitability for new purposes – such as castings for larger wind turbines.

Example(s) of Common Student Ideas:

- Emergent technologies use the same resources as existing technologies.

8.ESS3.1 – Interpret and explain that Earth's mineral, fossil fuel, and groundwater resources are unevenly distributed as a result of geologic processes.

Big Ideas:

Geologic processes do not occur uniformly across and below Earth's surface. The distribution of natural resources will, therefore, be non-uniform because the processes that accumulate the resources are not uniform.

Scientific Ideas:

- Earth's mineral, fossil fuel, and groundwater resources form/accumulate because of large-scale geologic processes.
- Mineral, fossil fuel, and groundwater resources form/accumulate over geologic scales of time.
- Some resources only form under certain environmental conditions (e.g., prehistoric coal deposits form after periods of plant proliferation).
- Non-renewable resources have an uneven distribution because the processes that form the resources are not uniform.
- Renewable resources do have an uneven distribution because conditions on Earth's surface vary (e.g., the Sun's energy does not reach all parts of the Earth evenly, plants used for biofuels require certain environmental conditions to thrive).

Example(s) of Common Student Ideas:

- The composition of the ground beneath Earth's surface has a uniform composition.
- An aquifer is a giant water-filled cave deep under Earth's surface.
- There is no space between particles that make up Earth's crust.

Revised (2025 Implementation): 6.ESS3.1, 6.ESS3.2

6.ESS3.1 – Use data to explain the consumption and sustainability of natural resources (non-renewable and renewable) and the resulting impact on Earth's system.

6.ESS3.2 – Investigate and compare existing and developing technologies that utilize renewable and alternative energy resources.

ESS3.B: Natural Hazards

Guiding Question:

How do natural hazards affect individuals and societies?

The Biggest Ideas

PURPOSE

The theme across all component ideas within the larger disciplinary core idea are the ways that Earth's processes affect humans and are, in turn, affected by humans.
This component idea explores the effects of natural hazards on humans and the ways that human activities can impact the frequency and severity of some events.

CENTRAL IDEA(S)

Natural processes can create sudden or gradual changes to Earths systems. Some of these changes can be negative. Humans cannot eliminate hazards, but it is possible to make decisions that minimize the negative effects. It is possible to design warning systems for some types of natural hazards. Human activities can cause some natural hazards to become more intense or more frequent.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression begins with students exploring natural hazards that are related to weather, how scientists can predict them, and how the steps people take to lessen their effects. In late elementary school students will look at other types of natural hazards, including examples that they might not experience firsthand. Students should come to understand that these hazards may affect them directly or indirectly. In middle school, students apply their understanding of physical science and Earth's systems to consider mechanisms that cause various natural hazards. Students learn that it is possible to make predictions about potential natural hazards when we understand the mechanisms or using data about past natural hazards.

K-2 Standards

By the end of grade 2. Some kinds of severe weather are more likely than others in a given region. Weather scientists forecast severe weather so that communities can prepare for and respond to these events. – NRC, 2012

Progression Across Grade Bands:

The goal for this progression is to understand the ways natural hazards impact people, people can minimize the negative effects of natural hazards, and human activities can affect the frequency and intensity of natural hazards.

This progression begins with natural hazards related to weather and should explore weather events where students have firsthand experiences. Common severe weather examples such as thunderstorms, tornadoes, and floods, may be traumatic for students and, if used, should be addressed with sensitivity. Students are more likely to have experiences with other forms of severe weather such as types of winter weather, heavy rains, or extreme heat.

Students are also more likely to relate to measures such as "snow days" as a way that their communities may attempt to reduce the impact of these forms of severe weather. In later grades, students will learn more about the causes of severe weather and how these causes relate to natural processes.

Current (2018 Implementation): K.ESS3.2

K.ESS3.2 – Explain the purpose of weather forecasting to prepare for, and respond to, severe weather in Tennessee.

Big Ideas:

Tennessee is one place on Earth. Weather forecasters can predict the types of severe weather it may experience based on its history.

Scientific Ideas:

- Tennessee is a place where people live. It has boundaries and features that make it unique from other places. It also has features that make it like some other places.
- Throughout Tennessee's history, people have produced records of diverse types of severe weather that have occurred here – personal journals, planting journals, newspaper articles, stories on the internet, draught monitors, etc.
- Records contain evidence and reveal patterns showing that some types of severe weather happen more frequently than others.
- Weather forecasters use patterns to predict when severe weather is more/less likely to happen.

- People use weather forecasts to make decisions, prepare for and respond to events (e.g., clothing choices, burn bans, reducing water usage, opening cold shelters, snow days, closing roads for high water).
- Severe weather that happens in one part of Tennessee, may not happen in all parts of Tennessee. Tennessee communities are connected. When events affect one community, other communities come out to help support neighbors.
- Some types of severe weather have impacts to a large area (a hot, dry summer might mean that landscapers in a whole community may lose money if lawns need mowing less often), other types of severe weather may only impact in only a small area (a landslide may impact traffic, but without damaging homes).

Example(s) of Common Student Ideas:

- Severe weather will always occur when it is predicted.
- Weather forecasts aren't always right, so it is safe to ignore them.

Revised (2025 Implementation): K.ESS3.2

K.ESS3.2 – Explain the purpose of weather forecasting to prepare for, and respond to, severe weather in Tennessee.

3-5 Standards

By the end of grade 5. A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions, severe weather, floods, coastal erosion). Humans cannot eliminate natural hazards but can take steps to reduce their impacts. – NRC, 2012

Progression Across Grade Bands:

In early elementary the standards focus on severe weather and most of the discussions should have focused on the types of weather students might encounter in Tennessee. Discussions included the ways that people prepare for severe weather and the idea that severe weather is predictable to a certain degree.

In late elementary school, standards expanded the idea of natural hazards to include more types of natural hazards, including some that students may never experience firsthand. In ESS3.A, students are learning that the materials they use are all derived from natural sources which may not be available in their local communities. Students can consider that even disasters that do not happen in their community, may still affect them. For example, the price of some of the things that they buy might go up because we buy many things that come from other parts of the world. Since we know that natural hazards will occur, it is important that we plan for their occurrences and try to minimize our losses when they happen.

Current (2018 Implementation): 3.ESS3.1, 3.ESS3.2

3.ESS3.1 – Explain how natural hazards (fires, landslides, earthquakes, volcanic eruptions, floods) impact humans and the environment.

Big Ideas:

Natural hazards have effects that can be short term and long term as well as widespread or local.

Scientific Ideas:

- The way someone experiences the effects of natural hazards depends on where they live.
- Not all places experience the same types of natural hazards. Some places may experience certain types of natural hazards very infrequently or not at all.
- Physical loss is one type of impact from a natural hazard.
- Because communities/societies/economies are connected natural hazards can affect people outside of the immediate area.

Example(s) of Common Student Ideas:

- Since [a certain type of natural disaster] does not occur where I live, I do not need to think about how it might impact me.

3.ESS3.2 – Design solutions to reduce the impact of natural hazards (fires, landslides, earthquakes, volcanic eruptions, floods) on the environment.

Big Ideas:

The more we learn about natural hazards the better we can prepare for them. Preparations include being able to predict when a hazard might happen as well as the way we build and the plans that we make for when a hazard occurs.

(Note: Solutions do not need to be physical devices. Solutions can also include things like safety plans, warning systems, etc. In any case it is important to identify criteria and constraints for a successful solution as part of the problem definition.)

Scientific Ideas:

- Natural hazards are caused by natural processes/events. As people study natural processes so that they can be better prepared for natural hazards.
- Natural hazards are unavoidable, but humans can cope better if they take steps to reduce the impact of the hazards.
- Designing solutions to reduce the impacts of natural hazards requires an understanding of the natural processes and events that take place during a particular natural hazard.
- Some natural hazards have warning signs that may make it possible to predict the hazard or possible hazard before it occurs.
- Natural hazards can have impacts beyond the area they directly impact. All communities should consider potential impacts for types of natural hazards they may not experience directly.
- Plans to reduce the impact of a natural hazard can include preparation ahead of the event, safety during the event, and/or recovery after the event.

Example(s) of Common Student Ideas:

- Design solutions are always physical devices.

Revised (2025 Implementation): 3.ESS3.1

3.ESS3.1 – Evaluate existing solutions that reduce the impact of natural hazards (e.g., fires, landslides, earthquakes, volcanic eruptions, floods, severe weather) on the environment.

6-8 Standards

By the end of grade 8. Some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions. Others, such as earthquakes, occur suddenly and with no notice, and thus they are not yet predictable. However, mapping the history of natural hazards in a region, combined with an understanding of related geological forces can help forecast the locations and likelihoods of future events. – NRC, 2012

Progression Across Grade Bands:

In the middle grades, student thinking about natural hazards expands from thinking about what hazards are and how we can mitigate losses, to also thinking about how our understanding of Earth's systems allows us to prepare for and predict natural hazards.

By middle school, students have enough background about topics, such as energy, ocean circulation, properties of matter, plate tectonics, etc., that it is possible for students to begin to think about the mechanisms for various natural disasters. Students can apply their understanding of the mechanisms driving various natural hazards that they can reason whether hazards may or may not be predictable.

Some threads from earlier grades continue such as the idea that data is a tool that enables prediction. As students come to understand that some natural hazards cannot be predicted based on understanding the mechanism, they should also learn that it is still possible to predict the likelihood of certain natural hazards. For example, even though we understand the forces that cause earthquakes we cannot predict them. However, there are places where Earthquakes are not likely, as well as places where earthquakes are more common.

Current (2018 Implementation): 8.ESS3.2

8.ESS3.2 – Collect data, map, and describe patterns in the locations of volcanoes and earthquakes related to tectonic plate boundaries, interactions, and hot spots.

<u>Big Ideas:</u>

The more we understand about how natural systems work, the better we can prepare for and predict where/when natural hazards might occur.

<u>Scientific Ideas:</u>

- The locations of volcanoes, earthquakes, and tectonic events occur in patterns.
- It is possible to predict some types of natural hazards by monitoring the conditions of Earth's systems. For volcanoes, scientists can track the upwards movements of magma.

By studying the events humans have been able to develop plans to reduce possible losses.

- It is not possible to predict when an earthquake might happen, however by looking at maps and historical records it is possible to know where earthquakes may happen or where they are not likely.
- Humans use data about past natural hazards to inform the way they build in places that have a history of volcanic or tectonic events. Some communities are more vulnerable to the impacts of natural hazards.
- Scientific predictions are based on the information we know about how Earth's systems will act and have acted in the past, but they are not certain.

Example(s) of Common Student Ideas:

- It is possible to predict when earthquakes will happen.
- Earthquakes are equally likely everywhere on Earth.

Revised (2025 Implementation): 8.ESS3.1

8.ESS3.1 – Collect data, map, and describe patterns in the locations of volcanoes and earthquakes related to tectonic plate boundaries, interactions, and hotspots in order to forecast the locations and likelihoods of future events.

ESS3.C: Human Impacts on Earth Systems

Guiding Question:

How do humans change the planet?

The Biggest Ideas

Purpose

The theme across all component ideas within the larger disciplinary core idea are the ways that Earth's processes affect humans and are, in turn, affected by humans.
The goal for this component idea is for students to explore ways that humans change areas on and near Earth's surface which also affect other Earth systems. The changes caused by humans affect the course of human civilizations.

Central Idea(s)

Throughout history, human actions have had effects on Earth's systems. Individuals can take actions to reduce their impact on Earth's systems. As humans began to form communities their effects on the environment became larger. Communities can implement systems to reduce their impact on Earth's systems. Humans affect the biosphere as well as other systems, but humans can develop technologies that can reduce as well as remediate past and present changes to Earth's systems.

General Progression for the Component Idea

Students begin this progression by considering the ways that they impact their environment and individual decisions they can make to lessen their effects. Later, students consider scale and how the activities of humans in groups have more significant effects on Earth. In the middle grades students consider the effects humans have had directly on the biosphere as well as indirect effects on the biosphere. Students also progress from thinking about solutions that reduce the impacts of human activities to ways that humans can remediate past changes.

K-2 Standards

By the end of grade 2. Things that people do to live comfortably can affect the world around them. But they can make choices that reduce their impacts on the land, water, air, and other living things—for example, by reducing trash through reuse and recycling. – NRC, 2012

Progression Across Grade Bands:

Most living things make decisions to stay alive. Humans are different. When humans have met their basic needs, they may do things to make their lives more comfortable and convenient.

Students can consider things they do that make their lives more comfortable and the effects of these actions on their local surroundings. For example, purchasing bottles of water can be a convenience in communities with safe drinking water. Students should understand that it is possible to enjoy conveniences and reduce possible negative impacts. Reusable water bottles filled with filtered tap water can reduce the amount of trash. Activities such as guided monitoring and inventorying different types of trash (paper, plastic, etc.) at home or in the cafeteria or collecting litter around campus can provide a way for students to see the different types of trash that they generate at home or at school and consider ways to reduce some types of trash and litter.

In later grades, standards become more complex by exploring how more people working as a group and larger population sizes amplify the effects humans have on the environment. The best activities for this standard will involve students taking direct actions and lead to outcomes that students can observe firsthand.

Current (2018 Implementation): K.ESS3.3

K.ESS3.3 – Communicate solutions that will reduce the impact from humans on land, water, air, and other living things in the local environment.

Big Ideas:

The things we do each day will always have effects on our local environment, but we can also do things that reduce our impacts.

Scientific Ideas:

- People depend on the places where they live to meet their needs and to be comfortable.
- People interact with different parts of their environment - land, water, air, and other organisms.
- We can use land and water to grow plants and some of these plants provide us with food.

- Living things (plants and animals) need to have clean air and clean water.
- People do things that have effects on other living things. (e.g., soil gets compacted in the places we play or paths we walk, trash and pollution can affect air and water quality).
- Individuals can build things (positive and negative) on Earth that may last for a very long time (e.g., 3D printing).
- People can make choices that will reduce their impact on Earth's other systems. We can find new uses for things or pass them on to others when we are done with them.
- Sometimes the choices that help reduce people's impact on the environment may mean that we must do extra work. (e.g., It takes extra work separating trash to make compost or recycling, we can save resources if we remember to turn off lights when we leave or water when we brush our teeth.)
- Choosing the best possible solution should involve considering the benefits and the extra work that is involved in each potential solution.

Example(s) of Common Student Ideas:

- As long as we pick up our trash, humans do not have an effect on the local environment

Revised (2025 Implementation): K.ESS3.2

K.ESS3.3 – Communicate solutions that will reduce the impact from humans on land, water, air, and other living things in the local environment.

3-5 Standards

By the end of grade 5. Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments. For example, they are treating sewage, reducing the amounts of materials they use, and regulating sources of pollution such as emissions from factories and power plants or the runoff from agricultural activities. – NRC, 2012

Progression Across Grade Bands:

Sometimes when humans have met their basic needs, they do things to make their lives more comfortable. In earlier grades students considered some things they might do, such as the types of trash they generated, and ways that they could enjoy comforts in ways that have less impact on their surroundings.

This progression develops by considering the scale of human actions. In early human history, hunter-gatherer humans depended on foraging and hunting to survive. As humans began to manage plants and animals for their benefit, it was possible to develop larger communities. Developments in agriculture have made it possible to support larger communities and civilizations, but have also increased the effects on the environment – chemical pollution, increased erosion, etc. The scale of these effects became even greater has machines replaced manual labor. Obtaining and refining the material needed to make machines caused humans to seek out new types of resources which created new types of impact on the land and oceans.

There are positive effects to large scale human activities. Larger scales provide ways to meet the needs of more people. Additionally, positive actions are more effective at scale; The effects of individual actions have greater consequences when more people make the same decisions. Students should also explore the ways that communities can implement programs and services in ways that make better use of resources and lessen the effects of people on the environment. In later grades, students will explore ways that technologies can reduce the impact of human activities.

Current (2018 Implementation): 4.ESS3.2

4.ESS3.2 – Create an argument, using evidence from research, that human activity (farming, mining, building) can affect the land and ocean in positive and/or negative ways.

<u>Big Ideas:</u>

When a group of people make similar decisions, their collective impact on earth's systems is greater than their individual impact.

Scientific Ideas:

- Humans depend on their environment to meet their needs and desires for comfort.
- Throughout history, humans have acted in ways that have had major effects on all of Earth's systems, and beyond into space.
- People (living organisms) form groups and work in groups to meet the needs of the individual. Industries such as farming for food, mining for natural resources, and building things like homes and roads are all examples of ways that people work together.
- Human impacts on the local environment are more significant when a group of people make the same decision (e.g., littering along roadsides).
- Human impacts positive and negative on the local environment have the potential to be more significant when people scale up their efforts to meet the needs of a group of people (e.g., larger scale farming at a single site can increase efficiency but requires larger continuous segments of land).
- Individuals can work as groups and when they cooperate or a group of people make the same decision, the group can have a much greater effect than an individual.

Example(s) of Common Student Ideas:

- The oceans are so large, that human activities cannot change them.

Revised (2025 Implementation): 4.ESS3.2

4.ESS3.2 – Engage in an argument, using evidence from research, that human activity (e.g., farming, mining, building) can affect the land and ocean in positive and/or negative ways.

6-8 Standards

By the end of grade 8. Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of many other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on *Earth unless the activities and technologies involved are engineered otherwise. – NRC, 2012*

Progression Across Grade Bands:

This progression has scaled from the effects of individuals (K-2) to the effects of groups of (3-5). Standards have centered on the idea that humans have needs and desires for comfort, humans use their surroundings to meet their needs, and even though this dependency is inevitable, it is possible to reduce the impacts that people have on their natural surroundings.

Students have learned that some species that once lived on Earth are no longer found here. Some of these extinctions have been caused by human activities due to factors such as loss of habitat. This may include habitat loss due directly to human activities such as destruction or development of habitat but can also be due to indirect human activities such as redirecting watersheds. The effects of human activities can be both positive and negative depending on the needs of affected organisms. Some changes may create conditions where a species may thrive in an environment changed by human actions.

In the middle grades students begin to explore examples of the ways that deliberate actions can counteract some of our past impacts – this is a progress from reducing impacts to remediating impacts. The need to reduce our impact becomes important when students see that as our populations have grown larger, individuals consume more relative to consumption when human populations were smaller. The types of materials that humans are using have also changed humans have developed new technologies.

Current (2018 Implementation): 6.ESS3.3

6.ESS3.3 – Assess the impacts of human activities on the biosphere including conservation, habitat management, species endangerment, and extinction.

<u>Big Ideas:</u>

Throughout our history, humans have made decisions that have had both positive and negative consequences. Through deliberate action, humans have been able to remedy some of their effects.

Scientific Ideas:

- Throughout history, human impacts have been so significant that they have resulted in complete losses – loss or fragmentation of habitat or even losses of entire species.
- When we change the environment, not all organisms will experience the changes in the same way. Changes that may be harmful to one organism can create opportunities for other species to thrive.
- Advances in technology (perpetuated through the application of scientific discovery) have led to new ways to reduce and counteract the negative changes on the environment.
- Deliberate efforts such as land conservation and habitat management attempt to reduce the impact of population growth on the environment.

Example(s) of Common Student Ideas:

- Human impacts on the biosphere only come from direct interactions with the biosphere, and not indirectly through other spheres.

Revised (2025 Implementation): 6.ESS3.3

6.ESS3.3 – Obtain, evaluate, and communicate information about the impacts of human activities on the biosphere including conservation, habitat management, species endangerment, and extinction.

ESS3.D: Global Climate Change

Guiding Question:

How do people model and predict the effects of human activities on Earth's climate?

The Biggest Ideas

PURPOSE

The theme across all component ideas within the larger disciplinary core idea are the ways that Earth's processes affect humans and are, in turn, affected by humans.
The goal for this component idea is for students to explore the ways that changes to Earth's climates affect living things as well as factors that can cause changes to Earth's future climate.

CENTRAL IDEA(S)

Most changes to Earth's systems happen so slowly that we do not notice them. Over our history, humans have developed new technologies that allow us to make and store a variety of measurements about Earth's past. Scientists combine this accumulated data with our growing understanding of chemistry and physics to develop models that predict how Earth's climate will change in the future. These predictions help us plan for growing populations, but also contain uncertainties associated with both the underlying science and our ability to predict how human behaviors may change.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression begins in late elementary when students consider how animals and human communities may be affected by warming temperatures. In middle school students consider and evaluate sources of data that relate increasing levels of greenhouse gases with human activities and a mechanism to explain how these factors can lead to warming climates.

K-2 Standards

By the end of grade 2: [Intentionally left blank] – NRC, 2012

Progression Across Grade Bands:

In this grade band, students should have firsthand experiences that support the science concepts they are learning. However, the foundational ideas for this component idea are large – Earth's systems, population growth. Students also need to be able to observe trends in data that exceed K-2 math standards. Due to these disparities, there are no standards in this component idea until later grades. Students are learning about weather (ESS2.D) and the ways that humans affect their environment overlap with this component idea.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

3-5 Standards

By the end of grade 5. If Earth's global mean temperature continues to rise, the lives of humans and other organisms will be affected in many different ways. - NRC, 2012

Progression Across Grade Bands:

Multiple data sets support that Earth's global mean temperature is rising. While adults may have firsthand experiences with warmer temperatures where they live or have lived in the past, younger students are not likely to have accumulated these experiences. It may help students to support the claim of rising temperatures with other lines of evidence. Students know that the Sun warms Earth's surface and that surfaces reflect or absorb heat differently. They can understand that Earth will absorb more of the Sun's energy if there is less snow and ice to reflect the light back into space.

Students know that some places can be too hot/cold, or wet/dry for things to live there. Temperature changes may lead to changes that make it hard for organisms to live in places where they have typically lived. For example, dry summers affect the growth of milkweed plants which then affect the migration patterns of monarch butterflies that depend on milkweed as their only larval food source.

Students can build on their understanding of the gases. Warmer temperatures allow the air to hold more water vapor. When the air can hold more water some areas may experience typical amounts of surface evaporation, but less rainfall, leading to dryer weather. Dryer weather affects human agriculture and over living things. As the wet air masses travel to different places, those places receive heavier rainfall and flooding becomes more common.

Students can consider firsthand experiences to see how differences of only a few degrees impacts their lives – a few degrees of difference may mean the difference between snow/ice/rain in the winter, when it is warm enough to take a blanket off the bed, or when plants can be moved outside in the spring.

Current (2018 Implementation): No Standard

There is not a standard written specifically for this collection of ideas in grades 3-5.

Revised (2025 Implementation): No Standard

There is no standard written specifically for this collection of ideas in grades 3-5, however some of the ideas will overlap with ideas covered in 4.LS2.4.

6-8 Standards

By the end of grade 8. Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.
– NRC, 2012

Progression Across Grade Bands:

Tennessee science standards introduce this progression for the first time in middle school. The 3-5 progression (above) describes some foundational ideas that may need to be covered in middle school.

People have historical data about the atmosphere and continue to add to these data. These data include temperature measurements from more recent human history and data taken from ice and rock samples. Although the amount of carbon on Earth has been consistent, levels of greenhouse gases have risen and fallen throughout Earth's history. Much faster rates of change coincide with some human activities, such as increased use of fossil fuels. The rise of greenhouse gases coincides with a rise in Earth's surface temperature. An understanding of how Earth traps and releases energy from the Sun explains how the rise in greenhouse gases can contribute to a warmer Earth.

As with natural hazards, humans can make decisions that can help limit the effects of any future climate change. As our understanding of all fields of science increases, we gain a clearer picture of how Earth's different systems interact.

Current (2018 Implementation): 7.ESS3.1, 7.ESS3.2

7.ESS3.1 – Graphically represent the composition of the atmosphere as a mixture of gases and discuss the potential for atmospheric change.

<u>Big Ideas:</u>

A variety of chemical reactions across Earth's systems have changed the composition of Earth's atmosphere in the past and will continue to cause changes to the atmosphere.

<u>Scientific Ideas:</u>

- Matter exists as gases, including most that are not visible. The atmosphere is a region of space above our planet where Earth's gravity prevents these gases from escaping into outer space.

- Elements combine to form different compounds. These compounds have unique chemical properties which influence whether they exist on Earth as solids, liquids, or gases.
- Some atoms of a given element may be incorporated into a compound that is a gas and becomes part of the atmosphere, while other atoms of the same compound may be incorporated into compounds that are solid and less likely to become part of the atmosphere. (e.g., nitrogen may exist as nitrogen gas (N_2) or ammonia (NH_3) which are both gases that are part of Earth's atmosphere, but it can also exist in compounds containing ammonium (ammonium nitrate, NH_4OH) that are solids on Earth, or as part of proteins which are a component of tissues.
- The physical properties of water interact with conditions (temperature and pressure) on earth in such a way that water exists a solid, liquid, or gas on earth and therefore it can move into or out of the atmosphere more readily than most compounds.
- Evidence shows that there have been changes to Earth's atmosphere in the past. For example:
    - "Red beds" form when there is oxygen gas (O_2) in the atmosphere allowing iron and oxygen react to form rust. The earliest layers of sediment do not contain red beds. The appearance of red beds marks the point where oxygen became prevalent in the atmosphere.
    - The present-day coal beds that formed during the carboniferous period formed as plants pulled carbon (in the form of carbon dioxide) from the atmosphere.
- The chemicals that move in and out of the atmosphere (e.g., carbon is added to the atmosphere as carbon dioxide and methane, but plants remove it when they make sugars, a variety of microorganisms move nitrogen between living systems, the soils, and the atmosphere.)
    - Note: Students are not expected to know specifics of these biogeochemical processes, only the big idea that the atmosphere's composition changes because of these cycles.
- Human activities that utilize fossil fuels release carbon back into the atmosphere from other stores.

<u>Example(s) of Common Student Ideas:</u>

- All forms of carbon exist in the same phase – solid, liquid, or gas.
- The composition of the atmosphere is uniform.
- The types and amounts of gases in Earth's atmosphere have been the same throughout Earth's history.

7.ESS3.2 – Engage in a scientific argument through graphing and translating data regarding human activity and climate.

<u>Big Ideas:</u>

Our atmosphere regulates our climate as it maintains a balance between energy inputs from the sun and outputs back to outer space. Human activities that alter the composition of the atmosphere and its ability to maintain this balance.

Scientific Ideas:

- Light transfers energy. We can see some types of light – the visible spectrum – but are unable to detect other forms of light with our senses – ultraviolet and infrared.
- Earth's systems receive energy from the Sun. This energy warms Earth's surface.
- Earth's atmosphere regulates its surface temperature and protects living organisms from high energy light from the sun that would damage living tissues.
- During the day, the light from the sun adds energy to Earth as it warms surfaces. This energy is stored as thermal energy in matter. At night, matter cools releasing the stored energy as infrared light.
- Earth's atmosphere behaves like a blanket. Particles in the lowest portion of the atmosphere absorb some of the released surface energy. This layer retains a portion of this energy (it is temperature increases) and gives off a portion of this energy to the subsequent layer. At the top of the atmosphere, a portion of the energy is emitted into space. Below this point, the temperature of each lower layer increased slightly because of the energy transfer.
- A stable climate is maintained by a balance in the energy inputs from the sun compared to energy losses through radiation through the atmosphere.
- Several specific molecules that exist as gases (e.g., water vapor and carbon containing molecules such as methane and carbon dioxide) play a significant role in establishing Earth's climate. These gases occur naturally, but a variety of human activities have increased their proportions in the atmosphere.
- Human activities have shifted some of these greenhouse gases from earthbound stores (e.g., biomass and fossil fuels) into the atmosphere. Increasing the proportion of these gases in the atmosphere reduces the Earth's ability to release energy back into space.
- Some surfaces on Earth are naturally reflective – including ice and snow. These surfaces absorb less of the Sun's energy and reflect a larger portion of the Sun's energy back into space. Warmer temperatures cause the area of Earth's surface covered by these surfaces to decrease. This decrease creates a positive feedback loop – more melting causes warmer temperatures and warmer temperatures causes more melting.

Example(s) of Common Student Ideas:

- If human activities were impacting the atmosphere, then the effects would be immediate and dramatic.
- Earth is such a large system, that it is able to absorb the effects of human activities.

Revised (2025 Implementation): No Standard

There is no standard written specifically for this collection of ideas in grades 6-8, however some of the ideas will overlap with ideas covered in 6.ESS2.6.

ETS1.A: Defining and Delimiting Engineering Problems

Guiding Questions:

What is a design for?

What are the criteria and constraints of a successful solution?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to explore the first stage of an engineering process. This is the problematizing phase where students develop a design problem in response to a need that has been identified.

The ETS1 Disciplinary Core Ideas introduce specialized knowledge that defines an engineering process – problematizing (ETS1.A), solution design (ETS1.B), and optimization (ETS1.C). The Science and Engineering Practices are used throughout the engineering process.

CENTRAL IDEA(S)

A situation that people want to improve can be approached as a problem to be solved through engineering. Solutions can be devices or processes. Engineers begin by defining the problem. The definition should clearly describe the goals (criteria) for a successful solution – things like the job/purpose, the cost, durability, etc. The problem should also define constraints that may limit the range of possible solutions – things like cost, size, weight, performance, etc. Problematizing also involves developing sets of questions that need to be answered before solution design can begin. For example, students may need to learn new scientific ideas, or details about the environment/context for the solution.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

Students learn that changing a situation involves creating a design problem. The purpose of the design problem is to describe the features of the possible solutions. A design problem must be defined before attempting to solve a design task. Students learn that a design problem should define criteria and constraints in the intermediate grades. Initially, students work with simple constraints based on materials and resources. By the middle grades students develop more specific criteria and constraints that incorporate scientific principles and are measurable, whenever possible.

K-2 Standards

By the end of grade 2. A situation that people want to change or create can be approached as a problem to be solved through engineering. Such problems may have many acceptable solutions. Asking questions, making observations, and gathering information are helpful in thinking about problems. Before beginning to design a solution, it is important to clearly understand the problem. – NRC, 2012

Progression Across Grade Bands

Engineering begins when someone wants to change a situation. The change may involve developing a device or creating/revising a process.

Changing a situation requires a clearly defined problem. Students should play a role in defining the problem for the situation they will change. Design-focused units, such as problem based learning units, should begin with student observations that identify a situation to improve. For example, a muddy classroom floor can show a need for cleaner shoes, hula hoop sampling for biodiversity can show that there aren't many different types of things living in the school yard, a map of temperatures around the school can show a need for shady places, messy areas around school might be caused by paper towels that do not land in waste baskets, etc. Teachers should support students to develop problems from their observations. Students miss some or all of the problematizing processes when they are given a task to complete (e.g., build a tower out of straws), instead of a situation to improve.

Overly prescribed problems also take away the opportunity for students to identify things they need to figure out to improve the situation. Teachers can lead students in the process of collecting and curating questions students need to answer to help design their solutions. This set of questions can guide their learning. For example, students can be led to understand absorption of different materials on Earth's surface if they need to understand why mud forms when water enters the ground, or students may need to design an investigation to figure out which textures/surfaces remove the most mud from their shoes.

Students should be learning that there can be many possible solutions for a defined problem. In the earliest grades students do not need to select the best/winning solution. Selecting a winning solution may contradict the idea that multiple solutions are possible. Students should learn to recognize and eliminate solutions that are not acceptable based on the defined problem.

In later grades, students will learn that the definition of a problem should include specific criteria for successful solutions and constraints that may limit possible solutions. Students will also compare possible solutions to criteria and constraints, identify relative strengths and weaknesses among solutions, and consider tradeoffs when recommending a solution.

Current (2018 Implementation): K.ETS1.1, 1.ETS1.1, 2.ETS1.1

K.ETS1.1 – Ask and answer questions about the scientific world and gather information using the senses.

Big Ideas:

It is not possible to fully understand a design problem without understanding the relevant context. Asking questions (e.g., clarifying questions), making firsthand observations, and gathering information are ways to help understand a design problem.

Scientific Ideas:

- People have situations (e.g., devices, processes) that they want to improve.
- People begin to change situations by writing design problems that describe the changes they want to see.
- Engineers must understand design problems before they begin to attempt to solve them.
- A design problem should describe the things that a successful solution can accomplish.
- A design problem should define factors that could limit possible solutions (e.g., a limited quantity of some building material).
- The environment where a solution will be used can cause limits on possible solutions (e.g., limited space, hot, cold, wet, dry, protected, frequently used).
- The properties of available materials may limit possible solutions. (e.g., dimensions, weight, strength, color).

Example(s) of Common Student Ideas:

- Scientists know facts and don't ask questions.
- Scientists have figured out everything about how the natural world works.

1.ETS1.1 – Solve scientific problems by asking testable questions, making short-term and long-term observations, and gathering information.

Big Ideas:

It is not possible to fully understand a design problem without understanding the relevant context. Asking questions (e.g., clarifying questions), making firsthand observations, and gathering information are ways to help understand a design problem.

Scientific Ideas:

- People have situations (e.g., devices, processes) that they want to improve.
- People write design problems to describe how they want to change some situation (e.g., device, process)

- Engineers must understand design problems before they begin to attempt to solve them.
- A design problem should describe the things that a successful solution can accomplish.
- A design problem should define factors that could limit possible solutions (e.g., a limited quantity of some building material).
- The environment where a solution will be used can cause limits on possible solutions (e.g., limited space, hot, cold, wet, dry, protected, frequently used).
- The properties of available materials may limit possible solutions. (e.g., dimensions, weight, strength, color).

Example(s) of Common Student Ideas:

- Scientists only answer questions, they don't ask them.

2.ETS1.1 – Define a simple problem that can be solved through the development of a new or improved object or tool by asking questions, making observations, and gathering accurate information about a situation people want to change.

Big Ideas:

Defining a design problem requires understanding the situation to be improved. This requires identifying questions that need to be resolved before defining the problem.

Scientific Ideas:

- People write design problems to define the way to change a situation.
- It is possible to learn about a situation by asking questions, making observations, or gathering information.
- Materials have different properties. It may be necessary to learn about how or where a tool or object will be used can help identify the best materials to be used.
- Different shapes have different purposes. It is necessary to learn how a tool will be used to figure out which shapes are best.
- Tools have different parts, and each part has a specific purpose. It may be necessary to learn about each part of a tool's design with different questions or observations.
- Users may have unique needs or preferences for a tool. It is necessary to learn about the user's unique needs or preferences.

Example(s) of Common Student Ideas:

- Problems are always things that have to be fixed.

Revised (2025 Implementation): K.ETS1.1, K.ETS1.3, 1.ETS1.1, 1.ETS1.2, 2.ETS1.1

K.ETS1.1 – Apply an engineering design approach to identify and solve practical problems.

K.ETS1.3 – Ask and answer questions about the scientific world and gather information using the senses.

1.ETS1.1 – Apply an engineering design approach to identify and solve practical problems.

1.ETS1.2 – Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved.

2.ETS1.1 – Apply an engineering design approach to identify and solve practical problems.

3-5 Standards

By the end of grade 5. Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. – NRC, 2012

In earlier grades students should have made observations that helped them identify a situation that could be improved. For example, students may have been led to notice that a particular planter around campus always seems to be full of weeds. The major idea in earlier grades was for students to see that engineering is useful when there is a situation that can be improved.

A child's imagination is powerful and can dream up solutions to problems that may be impractical or perhaps impossible based on the physical laws of the universe. This progression introduces the ideas of criteria and constraints in late elementary grades. The definition of a problem should include both criteria and constraints.

Criteria are the requirements for a successful solution. For example, criteria for a solution to the weedy planter mentioned above could include minimal upkeep, using plants to keep weeds out, and a total cost of less than twenty dollars. Students may need to rely on their observations to develop the criteria, such as their observations about the dry soil.

Constraints are considerations that may limit some possible solutions. Students learn about material constraints first. This can be framed by the question, "Do we have a limited supply or any materials and resources?" As with criteria, constraints may require students to observe the place where their solution will be implemented.

In earlier grades students observed that any problem may have more than one possible solution. Criteria and constraints provide a basis to compare multiple solutions. Students can evaluate whether proposed solutions meet the criteria and constraints that are part of the defined problem. It is possible to evaluate whether solutions meet some criteria and constraints before solutions are testable.

Current (2018 Implementation): 3.ETS1.1

3.ETS1.1 – Design a solution to a real-world problem that includes specified criteria for constraints.

Big Ideas:

A design problem should include criteria for a successful design solution and constraints that must be satisfied.

Scientific Ideas:

- Before beginning a design task, it is important to have a clearly defined problem.
- A design problem describes how a situation will change.
- An engineering problem includes two components: criteria and constraints.
- Criteria can be listed and include the specific details of what a successful solution should be able to do.
- Constraints are restrictions or limitations that create boundaries for successful solutions. In this grade band, the discussion of constraints is limited to more tangible materials and resources.
- Solutions can be compared by using the criteria and constraints are a reference point.
- It is possible to have multiple successful solutions for a design task when more than one solution achieves the criteria within the limitations of the constraints.

Example(s) of Common Student Ideas:

- Criteria and constraints are the same thing.

Revised (2025 Implementation): 3.ETS1.1

3.ETS1.1 – Design a solution to a real-world problem that includes specified criteria and constraints.

6-8 Standards

By the end of grade 8. The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions (e.g., familiarity with the local climate may rule out certain plants for the school garden). – NRC, 2012

Progression Across Grade Bands

In the earliest grades, students can have experiences defining a basic design problem for a situation where they have seen a need to improve a situation. Students should have begun to include criteria and constraints into the definitions of their design problems by late elementary school. In middle school, students should develop more precise constraints that consider more factors. These constraints may still include material and resource constraints, but also include constraints such as natural laws and more complicated details.

In middle school, students should problematize more complicated situations. Engineers typically work on design tasks that address situations that they did not uncover firsthand. By spending time creating a well-defined problem, it is more likely that the solution will meet the needs of the user. Whenever possible, the criteria should be measurable. It is easier to determine when a criterion has been achieved when solutions can be measured and compared to quantitative specifications.

Solutions may need to work in a variety of situations and environmental conditions. For example, a tank that holds compressed air or gas may be kept indoors or outdoors in direct sunlight. Engineers must understand and apply scientific understanding as they work to define criteria and constraints. In the given example, students must understand the way that gases behave as temperature changes and may need to investigate the way that different materials transfer heat before it is possible to fully define the engineering problem. As part of the problematizing phase, students should continue to have opportunities to identify questions they need to answer and knowledge they need to obtain before they can define the criteria and constraints.

Current (2018 Implementation): 6.ETS1.1

6.ETS1.1 – Evaluate design constraints on solutions for maintaining ecosystems and biodiversity.

<u>Big Ideas:</u>

A design problem should define constraints that may limit possible solutions.

Scientific Ideas:

- People use engineering and design to change a situation.
- Engineers must define/understand the design problem before attempting to design a solution.
- All engineering problems should list criteria that should be achieved by a successful solution and constraints that can limit the range of potential solutions.
- Constraints may be a result of a variety of factors, including availability of materials and resources, the conditions where the solution will be implemented, scientific principles and the physical laws of the universe, societal values.
- It is necessary to ask and answer questions before beginning a design task in order to help define relevant and appropriate constraints. (e.g., How often will this device be used? Do users of the device have any physical limitations?)

Example(s) of Common Student Ideas:

- Constraints are the physical limitations of an object (e.g., this toy car can only roll along very smooth surfaces).

Revised (2025 Implementation): 8.ETS1.1

8.ETS1.1 – Use a model of a device that incorporates an electromagnet to test solutions to a design problem with specific criteria and constraints.

ETS1.B: Developing Possible Solutions

Guiding Question:

What is the process for developing potential design solutions?

The Biggest Ideas

PURPOSE

The purpose for this component idea is to help students understand the processes involved in brainstorming, modeling, and performing preliminary tests of potential solutions.

The ETS1 Disciplinary Core Ideas introduce specialized knowledge that defines an engineering process – problematizing (ETS1.A), solution design (ETS1.B), and optimization (ETS1.C). The Science and Engineering Practices are used throughout the engineering process.

CENTRAL IDEA(S)

Potential solutions must meet defined criteria and constraints for a problem. Brainstorming can provide an initial collection of possible solutions. Sketches can communicate preliminary ideas. Models (e.g., prototypes and computational models) of solutions provide ways to test, communicate, and guide development of elements of a solution.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

Students begin this progression by making sketches or simple models of their solutions to communicate their ideas to others. Later in elementary school students will begin to produce models of their solutions that they can test. The purpose of these initial tests is to identify failure points in their designs. By middle school students continue to use models to test their solutions – including computer simulations. The purpose of their tests is to identify ways to improve their solutions. Tests may reveal features from multiple solutions that can be incorporated into an improved design.

K-2 Standards

By the end of grade 2. Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people. To design something complicated, one may need to break the problem into parts and attend to each part separately but must then bring the parts together to test the overall plan. – NRC, 2012

Progression Across Grade Bands

In component idea ETS1.A, students are learning how to define a problem based on their observations that lead to a situation that they want to change. Problems should have simple definitions in the earliest grades, such as basic descriptions of goals that solutions should accomplish. The progression for component idea ETS1.B is about the process of developing and testing solutions to a defined problem.

Designing solutions begins with an imaginative phase where engineers try to imagine what potential solutions could look like. Students should have the opportunity to dream up solutions individually and to share their solutions with a group. Some students may benefit from attempting to share and refine their ideas with a partner before sharing the ideas with a table group or larger group.

Students should create initial models to share their ideas. Models can be sketches, drawings, physical models (3D objects). Student models allow students to uncover gaps in their ideas and represent their ideas with something that they can describe and share with others. Sometimes it is not possible to resolve or represent all the parts of a solution in a single design task or drawing. When this happens the task can be broken apart and approached as multiple smaller tasks with individual solutions that can be put together in a single larger plan. In later grades, students will develop models that help them test aspects of their ideas.

The concept of parts and whole appears across subjects in this grade band (for example: part-part-whole mats and number bonds) – students are learning that parts (addends) can come together to make a whole number and that a whole organism is a collection of different external parts – structures. Students should learn that engineering solutions may also have different parts and that each part may require a separate design task. For example, the shovel consists of a handle and a spade. The whole thing could be made of wood or metal, but most designs break the task of designing a shovel into separate parts - designing a spade, designing a handle, and designing a way to secure them together. Similarly, designing a garden may require improving the parts; nourishing the soil by adding compost and selecting suitable plants for the place. Solutions for each part should consider the function of the individual part.

Current (2018 Implementation): K.ETS1.2, 2.ETS1.2, 2.ETS1.3

K.ETS1.2 - Describe objects accurately by drawing and/or labeling pictures.

Big Ideas:

Engineers use sketches and drawings to communicate their ideas for solutions to other people.

Scientific Ideas:

- People have situations that they want to change, and engineers try to change these situations using a design process.
- Design problems describe the way that people want to see a situation change.
- Engineers try to imagine possible ways to solve a design problem – the problem should be defined first.
- A solution is one idea for a way to solve a design problem.
- Engineers can use sketches and/or drawings to share their ideas with other people.
- Sketches and drawings can include labels.
- A label is usually a word or a short phrase linked to a part of a design by a line or arrow.
- Labels help other people understand the different parts of a design.

Example(s) of Common Student Ideas:

- Sketches must look perfect to be useful.

2.ETS1.2 - Develop a simple sketch, drawing, or physical model that communicates solutions to others.

Big Ideas:

Engineers can use physical models, sketches, and drawings to communicate and test their preliminary ideas.

Scientific Ideas:

- People have situations that they want to change, and engineers try to change these situations using a design process.
- Design problems describe the way that people want to see a situation change.
- Engineers try to imagine possible ways to solve a design problem – the problem should be defined first.
- A solution is one idea for a way to solve a design problem.
- Engineers can use sketches, drawings, and/or physical models to share their ideas with other people.
- Physical models are representations of solutions. Sometimes they are operational, other times they might just show how pieces of a solution fit together.
- Physical models allow for simple tests of possible solutions to see if a solution might work.

- Test results from physical models can be used to refine initial design ideas.
- Sketches and drawings can include labels.
- A label is usually a word or a short phrase linked to a part of a design by a line or arrow.
- Labels help other people understand the different parts of a design.

Example(s) of Common Student Ideas:

- Sketches must look perfect to be useful
- Sketches must show all parts of a device.
- Sketches can only show devices, and not processes.

2.ETS1.3 - Recognize that to solve a problem, one may need to break the problem into parts, address each part, and then bring the parts back together

Big Ideas:

Objects and processes are made of smaller parts and sometimes it is easier to share our ideas when we use separate drawings for each smaller part.

Scientific Ideas:

- People have situations that they want to change, and engineers try to change these situations using a design process.
- Design problems describe the way that people want to see a situation change.
- Engineers try to imagine possible ways to solve a design problem – the problem should be defined first.
- Complicated tasks can be broken down into smaller, simpler tasks that can be solved individually.
- A solution is one idea for a way to solve a design problem.
- Tasks that have been broken down into smaller tasks will have separate solutions for each smaller task.
- Each part (object/process) of the larger solution must come back together in a way where one piece does not cause another to stop working as intended.
- Engineers can use sketches, drawings, and/or physical models to share their ideas with other people.

Example(s) of Common Student Ideas:

- A problem is always something that needs fixing.
- It is not possible to break a problem into smaller problems.

Revised (2025 Implementation): K.ETS1.2, 1.ETS1.3, 2.ETS1.2

K.ETS1.2 – Use drawings and labels to communicate ideas and designs accurately.

1.ETS1.3 – Develop a simple sketch, drawing, or physical model that communicates solutions to others.

2.ETS1.2 – Recognize that to solve a problem, one may need to break the problem into parts, address each part, and then bring the parts back together.

3-5 Standards

By the end of grade 5. Research on a problem should be carried out—for example, through Internet searches, market research, or field observations—before beginning to design a solution. An often productive way to generate ideas is for people to work together to brainstorm, test, and refine possible solutions. Testing a solution involves investigating how well it performs under a range of likely conditions. Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.

There are many types of models, ranging from simple physical models to computer models. They can be used to investigate how a design might work, communicate the design to others, and compare different designs. – NRC, 2012

Progression Across Grade Bands

In the early grades students engaged in the first phase of solution design by producing simple sketches or physical models to communicate their initial solutions to their peers. Models were helpful ways for young students to demonstrate that they recognized that design problems can be a collection of smaller problems to be resolved individually and reassembled as a single solution. At the time, students were not expected to build testable models of their solutions. The most significant development for the late elementary grade band is that students should begin to develop models of their solutions.

Conducting research is part of the design process. Scientists make discoveries and engineers develop technologies that can provide new options for solutions that may not have been available previously. Students can conduct research to learn about new options for materials or processes. For example, the development of elastic fibers and materials has driven an evolution of slip-on shoes. Research may be necessary to understand the environment or conditions their design will encounter that were not incorporated in the initial constraints. Engineers need to review survey data or the findings from focus groups to understand the ways that people use a particular tool or process. Students may also do research to discover existing solutions to similar problems rather than completely “reinventing the wheel.”

In late elementary school students should begin to use models to test their solutions. At this point, the main purpose of the tests is to identify failure points in a design. Sometimes students may be able to test an entire solution, but it is often more practical for students to test their solution in parts. Physical models of part of their design can lead to mathematical models. For example, students attempting to design an improved mop for the cafeteria can develop models that show how much liquid different thicknesses of material can absorb.

Collaboration is part of the ideation process as well as the development process. In earlier grades students developed ideas individually and then shared their initial ideas with others. As students get older and communicate more effectively, they should have more opportunities to collaborate during solution development. Students may begin the development process by brainstorming solutions with others and synthesizing the group's ideas to share with a larger audience. As students develop and test models, they should share their results with others.

Current (2018 Implementation): 4.ETS2.1, 5.ETS1.1, 5.ETS1.2, 5.ETS1.3

4.ETS2.1 - Use appropriate tools and measurements to build a model.

<u>Big Ideas:</u>

Engineers build models to develop, share, and test their ideas.

<u>Scientific Ideas:</u>

- People have situations they would like to improve and define design problems to describe what the changes they want to see.
- Models (e.g., sketches, drawings, physical models) are a tool for engineers to communicate their ideas with others.
- Labels on drawings and sketches help communicate design ideas.
- During solution development, models provide a way to test ideas.
- Models can show all or part of a solution.

<u>Example(s) of Common Student Ideas:</u>

- A model must be a fully working version of the device.
- Models should not be built until all ideas are complete.

5.ETS1.1 – Research, test, re-test, and communicate a design to solve a problem.

<u>Big Ideas:</u>

It is often necessary for engineers to explore new materials and processes that they can incorporate into their solutions. Applications of new materials often require testing.

<u>Scientific Ideas:</u>

- People have situations that they want to change, and engineers try to change these situations using a design process.
- Design problems describe the way that people want to see a situation change.

- Engineers try to imagine possible ways to solve a design problem – the problem should be defined first.
- There are many existing solutions to design problems that can provide ideas for ways to approach a design problem. Research can reveal ways that other people have resolved similar design problems.
- New industries, materials and processes emerge constantly. Research can uncover new options for ways to solve a design problem.
- Drawings, sketches, physical models, and prototypes allow engineers to test and communicate elements of their designs with other people.

Example(s) of Common Student Ideas:

- It is not possible to test parts of a design until all parts are built.

5.ETS1.2 – Plan and carry out tests on one or more elements of a prototype in which variables are controlled and failure points are considered to identify which elements need to be improved. Apply the results of tests to redesign the prototype.

Big Ideas:

Building models of potential solutions provides a way to test elements of potential solutions. These tests can reveal specific parts of a potential solution that need to be redesigned.

Scientific Ideas:

- A prototype is a working model of all or part of a possible solution.
- In a controlled investigation, a single variable changes in each trial. The purpose of the controlled investigation is to understand how that variable affects the design.
- If one part of a design is a suspected failure point, then a controlled investigation can be designed to understand the limits of that part of the design.
- Controlled tests of an entire design solution can reveal a particular weak point in a design.
- When a failure point is identified, it is necessary to consider redesigning that part of the solution.
- Failure points may fall outside of the range of conditions for a possible design. It is necessary to understand the environment and range of conditions where a design may be used.

Example(s) of Common Student Ideas:

- Designs should never have failure points.
- It is possible to design a solution with no failure points.

5.ETS1.3 – Describe how failure provides valuable information toward finding a solution.

Big Ideas:

Failure and failure points in a design can provide specific parts of a design that need to be re-designed.

Scientific Ideas:

- Engineers design solutions to improve a situation with defined criteria and constraints.
- It is common for initial solutions to fail.
- Failure can include breaking, but also includes not meeting design criteria, satisfying constraints.
- It is important to attempt to identify a specific cause when a design fails. Systematic testing of a suspected cause provides evidence to support or refute the redesign of one element of a design.

Example(s) of Common Student Ideas:

- Designs should never have failure points.
- It is possible to design a solution with no failure points.

Revised (2025 Implementation): 3.ETS1.2, 5.ETS1.1

3.ETS1.2 – Apply evidence or research to support a design solution.

5.ETS1.1 – Plan and carry out tests on one or more elements of a prototype in which variables are controlled and failure points are considered to identify which elements need to be improved. Apply the results of tests to redesign the prototype.

6-8 Standards

By the end of grade 8. A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. In any case, it is important to be able to communicate and explain solutions to others. Models of all kinds are important for testing solutions, and computers are a valuable tool for simulating systems. Simulations are useful for predicting what would happen if various parameters of the model were changed, as well as for making improvements to the model based on peer and leader (e.g., teacher) feedback. – NRC, 2012

Progression Across Grade Bands:

The first thing that students learn in this progression is that they can use drawings and sketches to communicate their ideas for solutions. Later in elementary school, students begin to collaborate on the design and testing of solutions to problems with specified criteria and constraints.

Students' early tests were used to identify failure points in their designs – e.g., materials that were not strong enough, or processes that did not work. The important development in middle school is that students should use their test results to guide modifications to their solutions. Tests should have controls and each solution should be tested in the same way. Students should learn that a solution may take ideas from several solutions and recombine parts of these solutions, resulting in a solution that is better than any of the earlier attempts.

The word "systems" might refer to individual parts of a device (e.g., wire, batteries, switch, core in an electromagnet), steps in a process (e.g., measuring and mixing parts of a resin), or components in a natural system (e.g., predator, prey, and surroundings in an ecosystem). By middle school, students will model relatively complex systems. The interactions between components in the system can be specified in computer simulations. For example, computer models selecting different plant types in a designed habitat can model how populations change because of predators or the ability to find a mate.

Current (2018 Implementation): 6.ETS1.2

6.ETS1.2 - Design and test different solutions that impact energy transfer.

Big Ideas:

The purpose of testing a potential solution is to discover specific opportunities to improve a solution.

Scientific Ideas:

- People design solutions to meet specified criteria and constraints according to defined engineering tasks.
- People begin to design solutions by brainstorming possible solutions and conducting research to better understand the design task and ideas for solutions.
- People can use drawings, sketches, and models to communicate their ideas with others.
- Models (e.g., physical, mathematical, and computational) provide ways to test ideas for potential solutions.
- People should evaluate designs that fail in order to understand the reason that the failure occurred.
- When people uncover a specific cause for a design's failure, that part of the design should be revised.
- Individual parts of other people's designs can inspire solutions for failed portions in a potential solution.
- Controlled tests can reveal failure points in a design.
- If a failure point is found within a reasonable operating condition for a design, then that part of the design should be revised.

Example(s) of Common Student Ideas:

- It is never acceptable to use other people's solutions as part of your solution.

Revised (2025 Implementation): (Overlap with 8.ETS1.1)

ETS1.C: Optimizing the Design Solution

Guiding Question:

How can various proposed design solutions be compared and improved?

The Biggest Ideas

PURPOSE

The purpose of this component idea is to help students learn to select and improve on the "best" solution by evaluating tradeoffs among the possible acceptable solutions.

The ETS1 Disciplinary Core Ideas introduce specialized knowledge that defines an engineering process – problematizing (ETS1.A), solution design (ETS1.B), and optimization (ETS1.C). The Science and Engineering Practices are used throughout the engineering process.

CENTRAL IDEA(S)

There will usually be more than one solution that meets the criteria and satisfies constraints for a design problem. People may have different judgements about which solution is "best" depending on how they prioritize criteria and constraints. Many potential factors can cause a shift in priorities over time or in different conditions/environments. It may be necessary to select multiple solutions for the same design problem when the solutions are used in multiple contexts with different priorities.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression requires students to compare completed designs. The progression begins with students evaluating multiple designs by comparing parts of each design to identify strengths and weaknesses. After learning about criteria and constraints (ETS1.A), students evaluate designs to see whether they meet the criteria and satisfy the constraints. By middle school, students carry out more systematic testing of the acceptable solutions. The systematic testing should provide information about ways to improve the design of leading solutions.

K-2 Standards

By the end of grade 2. Because there is always more than one possible solution to a problem, it is useful to compare designs, test them, and discuss their strengths and weaknesses. – NRC, 2012

Progression Across Grade Bands

Students should have the opportunity to create and share sketches and representations of their ideas for potential solutions. By providing this opportunity, students can be led to realize that it is possible to have multiple solutions for a design.

The entry point for this component idea is evaluation – students begin to compare different solutions they have developed. A single solution will typically have smaller parts. One way for students to begin to compare different solutions is to compare different parts of each solution – for example, different wheel designs for a car may roll differently. Students can identify strengths and weaknesses of each part of the design. This overlaps with discussions in life science where students are learning that the bodies of organisms have a variety of external parts and in physical science where students are learning that small pieces can be arranged in different ways to make a variety of objects.

In later grades students will learn about criteria and constraints. Students will learn that there is not a single "best" solution. Judging the best selection depends on prioritization of criteria and constraints. By learning to evaluate and recombine elements of a design in the earlier grades they are preparing to learn to evaluate tradeoffs in criteria and constraints.

Current (2018 Implementation): 2.ETS1.4

2.ETS1.4 - Compare and contrast solutions to a design problem by using evidence to point out strengths and weaknesses of the design.

Big Ideas:

There can be more than one possible solution for a design task and each solution will have strengths and weaknesses.

Scientific Ideas:

- People use engineering to change a situation by designing new objects or processes.
- Solutions to an engineering problem will often have multiple parts or steps.
- Labels on sketches and drawings can help other people understand our ideas for different parts of an object or the sequence of steps for a process.
- Labels can highlight similarities and differences between multiple solutions.

- Students can compare two very different solutions to consider strengths and weaknesses between the two overall approaches.
- Students can compare similar solutions to a problem and compare strengths and weaknesses among specific parts of those solutions.

Example(s) of Common Student Ideas:

- There can only be one solution to any design problem.

Revised (2025 Implementation): 2.ETS1.3

2.ETS1.3 - Compare and contrast solutions to a design problem by using evidence to point out strengths and weaknesses of the design.

3-5 Standards

By the end of grade 5. Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.
– NRC, 2012

Progression Across Grade Bands

In earlier grades, students should learn that there are multiple acceptable solutions for any given task. Solutions often consist of smaller parts. Students may have had opportunities to compare different solutions by identifying strengths and weaknesses.

The idea of testing and models appears in both ETS1.B and ETS1.C. The distinction is the purpose of the testing. During the process of solution design (ETS1.B), students are testing preliminary ideas and/or individual parts of a solution to see if those ideas might work. For example, if a device must hold a certain amount of weight, then students may need to figure out how much weight a particular type of string can lift before it breaks.

Students learn about criteria and constraints for the first time in this grade band. The testing mentioned in ETS1.C refers to tests of a completed solution to ensure that it meets the design criteria and satisfies the constraints. An acceptable solution is a solution that meets the criteria and satisfies the constraints.

Current (2018 Implementation): 3.ETS1.2, 4.ETS1.1, 4.ETS2.2

3.ETS1.2 – Apply evidence or research to support a design solution.

Big Ideas:

Engineers perform tests and conduct research to evaluate design solutions.

Scientific Ideas:

- Successful design solutions must meet specified criteria and adhere to given constraints.
- Tests provide evidence that a design will meet the specified criteria.
- It may be necessary to collect information to determine whether a design adheres to design constraints.

Example(s) of Common Student Ideas:

- There is only one successful solution for any design problem.

4.ETS1.1 - Categorize the effectiveness of design solutions by comparing them to specified criteria for constraints.

Big Ideas:

Successful designs must meet the defined criteria and satisfy specified constraints.

Scientific Ideas:

- Design problems include specified criteria that must be met and constraints that may limit the possible solutions.
- Final solutions should be tested against criteria and constraints.
- There can be more than one acceptable solution when more than one design meets the criteria and satisfies the constraints.

Example(s) of Common Student Ideas:

- There can only be one solution to any design problem.
- A solution is acceptable if it meets the criteria, even if it does not adhere to constraints.

4.ETS2.2 - Categorize the effectiveness of design solutions by comparing them to specified criteria for constraints.

Big Ideas:

Successful designs must meet the defined criteria and satisfy specified constraints.

Scientific Ideas:

- Design problems include specified criteria that must be met and constraints that may limit the possible solutions.
- Final solutions should be tested against criteria and constraints.
- There can be more than one acceptable solution when more than one design meets the criteria and satisfies the constraints.

Example(s) of Common Student Ideas:

- There can only be one solution to any design problem.
- A solution is acceptable if it meets the criteria, even if it does not adhere to constraints.

Revised (2025 Implementation): 4.ETS1.1

4.ETS1.1 - Categorize the effectiveness of design solutions by testing and comparing them to specified criteria and constraints.

6-8 Standards

By the end of grade 8. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Comparing different designs could involve running them through the same kinds of tests and systematically recording the results to determine which design performs best. Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. This iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. Once such a suitable solution is determined, it is important to describe that solution, explain how it was developed, and describe the features that make it successful. – NRC, 2012

Progression Across Grade Bands:

In the intermediate grades, students began to write design problems that included defined criteria and constraints as part of component idea ETS1. A. In the same grade band, students began to test parts of their design. Some of the tests attempted to identify failure points (ETS1.B), while other tests revealed whether designs met specified criteria or satisfied the constraints (ETS1.C).

Students should understand there will be multiple acceptable solutions. In the middle grades students should begin to consider that although all multiple solutions may fulfill the given criteria and constraints, it is still possible to determine a "best" solution. Furthermore, the "best" solution is subjective and based on a prioritization of certain criteria and constraints. For example, deciding that cost is the biggest priority might favor one solution, however if convenience is more important than cost, then a different solution may win out. Tools such as decision matrices are useful during the process of selecting from among different acceptable solutions.

Current (2018 Implementation): 8.ETS1.1

8.ETS1.1 - Develop a model to generate data for ongoing testing and modification of an electromagnet, a generator, and a motor such that an optimal design can be achieved.

Big Ideas:

An optimized design can be made by combining the best performing aspects of multiple designs.

Scientific Ideas:

- Design problems include specified criteria that must be met and constraints that may limit the possible solutions.
- It may be necessary to develop more than one test for final solutions since some criteria may need to be evaluated individually.
- Some designs may perform well in some areas, but poorly in other areas.
- An optimized design can come from combining the best performing elements across multiple designs.
- When components from different designs are combined, the individual component may not function as well as they did in the original designs. It is necessary to test the revised designs.

Example(s) of Common Student Ideas:

- A single solution will be the best option for all users.

Revised (2025 Implementation): 6.ETS1.1, 6.ETS1.2

6.ETS1.1 - Design, evaluate, and improve a possible solution for maintaining biodiversity of ecosystems.

6.ETS1.2 - Design, construct, and test a device that either minimizes or maximizes thermal energy transfer by combining solutions or parts of solutions to solve a problem that can be communicated and explained to others.

ETS2.A: Interdependence of Science, Engineering, and Technology

Guiding Question:

What are the relationships among science, engineering, and technology?

The Biggest Ideas

PURPOSE

The purpose of this component idea is for students to understand the interplay between the fields of science and engineering, and the technologies that they use and develop.

CENTRAL IDEA(S)

Scientists and engineers work together in many different fields. The fields of science and engineering are interdependent; scientific discovery and understanding can enable engineers to develop new technologies. In turn, the new technologies developed by engineers can provide new ways for scientists to explore the world, leading to even more discoveries and new insights. Technologies developed for one field often lead to improvements in other fields.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This progression begins with students learning to use some basic tools (technologies) to make more detailed observations and measurements. They learn that both scientists and engineers use tools for similar purposes. As students acquire a growing number of scientific ideas, they can see the role that scientific discovery plays in the design of new technologies. Students learn that the knowledge gained by using new tools has led to many new science fields. These fields have led to improvements in different technologies and entirely new fields of engineering and design using a variety of manufactured materials.

K-2 Standards

By the end of grade 2. People encounter questions about the natural world every day. There are many types of tools produced by engineering that can be used in science to help answer these questions through observation or measurement. Observations and measurements are also used in engineering to help test and refine design ideas. – NRC, 2012

Progression Across Grade Bands

Students should learn that science grows from observations that lead to questions. During instruction students should learn to develop questions to help them understand things about the natural world. Students should learn that engineers produce tools, including tools that they can use to explore the natural world and answer some of their scientific questions. Some simple tools allow people to extend their senses.

Two major ways that scientists use tools are observation and measurement. Tools for observation allow people to notice things that they may not detect otherwise – details that are too small to notice with their senses. Students do not learn about the microscopic world until the 3-5 grade band, so tools like a magnifying glass are more appropriate in this grade band than a microscope. Students may not grasp that the things they are seeing in the microscope still exist even without the view afforded by the microscope. Students can use tools like a pan balance to compare the weights of different objects and develop systems of measurement using common objects and standard systems in later grades.

Engineers use many of the same tools as scientists for similar purposes. For example, students can use a pan balance to measure weight (e.g., of a part or of a maximum load) as they determine strengths and weaknesses of different solutions.

Current (2018 Implementation): K.ETS2.1, 1.ETS2.1, 2.ETS2.1

K.ETS2.1 - Use appropriate tools (magnifying glass, rain gauge, basic balance scale) to make observations and answer testable scientific questions.

Big Ideas:

All tools are examples of technology. Scientists use different types of tools to make observations and measurements.

Scientific Ideas:

- Technology refers to any tool made by humans by applying scientific knowledge.

- Even very simple tools often incorporate some sort of scientific understanding in their design. For example, the first magnifier required people to understand that polishing a surface could improve its transparency.
- Scientists make and record measurements to compare two different things or different events.
- Measurements include a value along with a non-standard unit for reference (e.g., the pencil is 4 paper clips long).
- There are simple technologies that improve people's senses. For example, people can use magnifiers to see small details or cones to hear faint noises.

Example(s) of Common Student Ideas:

- Technology only refers to electronic devices like phones, tables, computers, etc.

1.ETS2.1 - Use appropriate tools (magnifying glass, basic balance scale) to make observations and answer testable scientific questions.

Big Ideas:

All tools are examples of technology. Scientists use different types of tools to make observations and measurements.

Scientific Ideas:

- Technology refers to any tool made by humans by applying scientific knowledge.
- Even very simple tools often incorporate some sort of scientific understanding in their design. For example, the first magnifier required people to understand that polishing a surface could improve its transparency.
- Scientists make and record measurements to compare two different things or different events.
- There are simple technologies that improve people's senses. For example, people can use magnifiers to see small details or cones to hear faint noises.
- Measurements include a value along with some non-standard units for reference (e.g., the pencil is 4 paper clips long).

Example(s) of Common Student Ideas:

- Technology only refers to electronic devices like phones, tables, computers, etc.

2.ETS2.1 - Use appropriate tools to make observations, record data, and refine design ideas.

Big Ideas:

All tools are examples of technology. Engineers use different types of tools to make observations and measurements that help them refine their designs.

Scientific Ideas:

- Technology refers to any tool made by humans by applying scientific knowledge.
- Even very simple tools often incorporate some sort of scientific understanding in their design. For example, the first magnifier required people to understand that polishing a surface could improve its transparency.
- Scientists make and record measurements to compare two different things or different events.
- Measurements include a value along with a unit of measure. For example, the length of a pencil is 4 paperclips or 18cm.
- Objects that are used as non-standard units can vary – paper clips come in different sizes. Standard units of measure provide a widely understood reference with little to no variation.
- There are simple technologies that improve people's senses. For example, people can use magnifiers to see small details or cones to hear faint noises.

Example(s) of Common Student Ideas:

- Technology only refers to electronic devices like phones, tables, computers, etc.

Revised (2025 Implementation): K.ETS2.1, 2.ETS2.1

K.ETS2.1 - Use appropriate tools (e.g., magnifying glass, rain gauge, basic balance scale) to make observations and answer testable scientific questions.

2.ETS2.1 - Use appropriate tools to make observations, record data, and refine design ideas.

3-5 Standards

By the end of grade 5. Tools and instruments (e.g., rulers, balances, thermometers, graduated cylinders, telescopes, microscopes) are used in scientific exploration to gather data and help answer questions about the natural world. Engineering design can develop and improve such technologies. Scientific discoveries about the natural world can often lead to new and improved technologies, which are developed through the engineering design process. Knowledge of relevant scientific concepts and research findings is important in engineering. – NRC, 2012

Progression Across Grade Bands

Students should have already learned that scientists primarily use tools to make observations or measurements. Students may have used tools that enhanced their senses, but only to the degree that they could make more detailed observations about something they could see without the aid of the tools. For instance, students may use a magnifying glass to see individual strands of algae in a sample of pond water, but not a microscope to see microscopic organisms in the pond water.

Students can use more complicated tools in the intermediate grades. Students become familiar with new scales of the universe in the intermediate grades – from the vastness of space to the invisible world of particles and microbes. Scientists rely on the tools developed through engineering to make observations and measurements of these new scales. For example, thermometers measure the speed of particles in a liquid.

Students should see how scientific discovery played a critical role in developing each of these tools. For example, to understand how a thermometer works, students should understand that liquids contain particles, which move faster when they have more energy. Engineers cannot develop microscopes and telescopes without understanding that the path of light will change when it crosses from one medium (e.g., air) into another medium (e.g., glass).

Current (2018 Implementation): 3.ETS2.1, 4.ETS2.1, 5.ETS2.1, 5.ETS2.2

3.ETS2.1 - Identify and demonstrate how technology can be used for different purposes.

<u>Big Ideas:</u>

The development of one technology often leads to new technologies because people find new uses for a technology that was originally developed for a different purpose.

Scientific Ideas:

- Technology refers to any device, tool, material, etc. that has been developed by applying knowledge of the natural world.
- Engineers develop technologies for a specific purpose and are guided by an intentionally defined design problem.
- Engineers conduct research during the solution development process, and this can lead to ideas for new ways to use existing technologies.
- As people use an object or material, they may find new uses for technology.
- When people need to fix or repair something, they may not have the ideal materials on hand and can improvise their repairs using the things around them.

Example(s) of Common Student Ideas:

- The ideas of engineers and inventors are entirely original.

4.ETS2.1 - Use appropriate tools and measurements to build a model.

Big Ideas:

It is possible to communicate more information about an observation or design by using appropriate units and tools with greater precision.

Scientific Ideas:

- People can use sketches to communicate their ideas for a solution to a design problem. Sketches can include labels that name or describe a part as well as measurements.
- There are standard units of measure for different properties of an object. For example, inches are used to measure lengths, but not used to measure weight.
- Some properties have more than one unit of measure. For example, length can be measured in inches, centimeters, feet, etc.
- Selecting the unit of measure and measuring tool depends on the size (length, volume, weight, etc.) of an object.
- It is possible to explain some differences between multiple measurements of an object when two tools of different quality are used to make the measurements. For example, the marks on a particular ruler might be larger or harder to read. The pivot point on a balance may not move as freely.
- A measuring tool's precision refers to the smallest measurement that can be made with a tool. For example, a ruler that includes only inches is less precise than a ruler that includes both inches and marks for both inches and half inches. A ruler that includes whole inches, half inches, and quarters of an inch is even more precise.
- It is possible to explain some differences between multiple measurements of an object when two tools of different precision are used to make the measurements. For example,

the marks on one graduated cylinder may only include 5mL intervals, while another graduated cylinder might include 1mL intervals.
- It is possible to include more detailed information about an object when measurements are made more precise tools.

Example(s) of Common Student Ideas:

- There is only one unit of measure for each property (e.g., all rulers measure in inches, weight is always measured in pounds, etc.).
- The quality of a measuring tool does not matter.

5.ETS2.1 - Use appropriate measuring tools, simple hand tools, and fasteners to construct a prototype of a new or improved technology.

Big Ideas:

Engineers apply scientific knowledge to develop new technologies and tools.

Scientific Ideas:

- People have situations that they want to change or improve. Engineers define problems and develop solutions to address those situations.
- Prototypes are physical models that can be used to test and refine an idea.
- Most technologies are based on technologies that already exist but may be used for a different purpose.
- Scientists make discoveries and engineers apply scientific discoveries in ways that improve existing technologies.

Example(s) of Common Student Ideas:

- Engineers do not need to continue learning science once they begin working.

5.ETS2.2 - Describe how human beings have made tools and machines (X-ray cameras, microscopes, satellites, computers) to observe and do things that they could not otherwise sense or do at all, or as quickly or efficiently.

Big Ideas:

Engineers apply scientific principles to design tools that enable a variety of scientific discoveries.

Scientific Ideas:

- Humans have a variety of sense receptors that interact with specific types of inputs from the surroundings to make observations.

- There are ranges for each type of receptor. When an input falls outside of a certain range, humans cannot sense the stimulus. For example, there are amounts and frequencies of light that humans cannot detect, aromas or sounds that are too faint to be detected, etc.
- The human brain processes and makes meaning of the inputs from the body's sense receptors.
- Engineers apply scientific principles to design devices that are more sensitive than human senses.
- Engineered systems capture the same types of inputs as human senses. Engineers can design these systems to capture inputs beyond the range that humans can sense.
- Some systems respond immediately to the inputs, other systems store encode and store the data.

Example(s) of Common Student Ideas:

- The types of inputs (e.g., scent particles, light frequencies) that devices collect are types of inputs that are different from those that humans collect.

Revised (2025 Implementation): 4.ETS2.1, 5.ETS2.1

4.ETS2.1 - Explain how existing technologies have been designed or improved to increase their benefits, to decrease known risks, and to meet societal demands (e.g., artificial limbs, seatbelts, cell phones).

5.ETS2.1 - Use appropriate tools to make measurements and answer testable questions.

6-8 Standards

By the end of grade 8. Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. To design better technologies, new science may need to be explored (e.g., materials research prompted by desire for better batteries or solar cells, biological questions raised by medical problems). Technologies in turn extend the measurement, exploration, modeling, and computational capacity of scientific investigations. – NRC, 2012

Progression Across Grade Bands

Students have learned that tools used by scientists are developed by engineers who rely on the discoveries of scientists to design these tools. Scientists and engineers use tools to enable increasingly detailed observations and measurements.

Students may have already explored the way that scientific understanding is the basis for engineered tools. For example, when students understand that matter is made of particles and particles move at different speeds depending on temperature, they can understand elements of how a thermometer works. Students acquire more scientific ideas in middle schools and are able to understand the basis for increasingly complicated tools.

Scientific discovery enabled by new technologies has led to a proliferation of scientific fields. For example, the field of chemistry emerged when scientists learned that there was an unseen world of particles. Many more scientific fields have emerged in more recent history.

Current (2018 Implementation): 7.ETS2.1

7.ETS2.1 - Examine a problem from the medical field pertaining to biomaterials and design a solution taking into consideration the criteria, constraints, and relevant scientific principles of the problem that may limit possible solutions.

Big Ideas:

Some engineering problems have the potential to help many people. Engineers and scientists might choose to undertake these problems even when some relevant scientific principles are not fully understood. These efforts can lead to new discoveries.

Scientific Ideas:

- People have situations that they want to change or improve. Engineers define problems and develop solutions to address these situations.
- There are scientific principles associated with any design task and solution.

- Scientific principles can take the form of a constraint that might limit the prospect of some solutions.
- Scientific principles can help predict the behavior of the different components (e.g., materials, objects, processes) in a solution.
- It is necessary to identify which scientific principles may be relevant to a certain engineering problem or design task.
- Sometimes the understanding of a specific scientific topic is not sufficient to address a particular design challenge. This may require advancements in an entire field of science.
- Many scientific discoveries have occurred when people have attempted to solve engineering problems where there was not initially sufficient understanding of some relevant scientific idea.

<u>Example(s) of Common Student Ideas:</u>

- Engineers only attempt to solve solutions in fields where scientists have a strong understanding of the relevant scientific principles.
- Science and engineering are different fields and so scientists and engineers do their work separately.

8.ETS1.2 – Research and communicate information to describe how data from technologies (telescopes, spectroscopes, satellites, and space probes) provide information about objects in the solar system and universe.

<u>Big Ideas:</u>

There have been, and will continue to be, developments in the variety and quality of information that humans can gather about space. These improvements are driven by interplay of scientific discovery and development of new technologies.

<u>Scientific Ideas:</u>

- For nearly any technology there is an earlier form of the same technology.
- Research in one field of science can lead provide engineers with new ways to improve existing technologies. For example, materials scientists have been able to develop new materials that can be used to build spacecraft.
- Solutions from one field of engineering can lead to new solutions in seemingly unrelated fields of engineering. For example, improved manufacturing processes have allowed chip designers to produce smaller computer chips resulting in smaller space probes.
- New and improved technologies can lead to entirely new types of measurements and observations.
- New types of observations and measurements can lead to the emergence of new fields of science. For example, the field of cosmology emerged/expanded as scientists began to understand more about the properties of light.

Example(s) of Common Student Ideas:

- All telescopes are designed to view visible light.

Revised (2025 Implementation): 8.ETS2.1

8.ETS2.1 - Research and communicate information to describe how data from technologies (e.g., telescopes, satellites, space probes, seismographs) provide information about Earth and objects in space and how those scientific discoveries have in turn led to improved technologies.

ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Guiding Question:

How do science, engineering, and the technologies that result from them affect the ways in which people live? How do they affect the natural world?

The Biggest Ideas

PURPOSE

The goal of this component idea is for students to understand that science and engineering lead to new technologies and these technologies can have a variety of effects on the way that people live and on the natural world.

CENTRAL IDEA(S)

Humans can benefit from technologies that result from the collaborations of scientists and engineers. All tools and technologies will have effects on the natural world because all the things made by humans use materials from the natural world. New technologies can change the types of resources that humans use and impact the natural world in new ways.

GENERAL PROGRESSION FOR THE COMPONENT IDEA

This component idea begins with the idea that technologies designed by engineers applying scientific knowledge improve people's lives. Each technology uses materials from the natural world and therefore has an effect on it. In the intermediate grades, students explore the idea that technologies improve over time driven by ways to increase the benefits, decrease the risks, or in response to societal demands. The idea that technologies improve people's lives progresses as students see that technologies can change the way that people live. In middle school this component idea explores scale – what effects are there as more people use technology? And why might people respond in different ways to the same technology?

K-2 Standards

By the end of grade 2. People depend on various technologies in their lives; human life would be very different without technology. Every human-made product is designed by applying some knowledge of the natural world and is built by using materials derived from the natural world, even when the materials are not themselves natural—for example, spoons made from refined metals. Thus, developing and using technology has impacts on the natural world. – NRC, 2012

Progression Across Grade Bands

Technology refers to anything designed and made by humans. Even the simplest technologies have changed the way that humans live. For example, as humans learned to produce glass, homes began to incorporate windows that allowed light into homes but kept bugs and animals outside.

The technologies that humans develop rely on materials from the natural world and applying our observations. Glass behaves mainly like a solid that forms from melted sand. Humans learned that adding soda ash, a natural salt, to the sand made it possible to heat the sand to make it behave like a liquid and allow the glass to be formed. All our technologies use materials from the natural world and therefore, technologies have impacted the natural world – such as the impacts of soda ash mines.

Sometimes these materials can be used with very little change to the original material (e.g., wooden doors and hardwood floors) but other materials look very different from the original material they are sourced from, such as paper.

Current (2018 Implementation): 2.ETS2.2

2.ETS2.2 - Predict and explain how human life and the natural world would be different without current technologies.

Big Ideas:

People develop tools that make tasks easier. Making and using these tools have effects on the natural world.

Scientific Ideas:

- All of the things that we do can teach us about the natural world, and we can use what we learn whenever we build something. For example, our experiences teach us that a tall skinny tower of blocks is not very stable.
- Technology refers to any tool made by humans by applying scientific knowledge.

- All the tools that people make come from materials in the natural world.
- Sometimes the materials used to make things look very different from the original materials found in nature.
- There will be changes to a place whenever people gather materials from that place.
- Some materials that people gather will have bigger effects on the environment than other materials.

Example(s) of Common Student Ideas:

- Some manmade materials do not use materials from the natural world.

Revised (2025 Implementation): 2.ETS2.2

2.ETS2.2 - Predict and explain how human life and the natural world would be different without current technologies.

3-5 Standards

By the end of grade 5. Over time, people's needs and wants change, as do their demands for new and improved technologies. Engineers improve existing technologies or develop new ones to increase their benefits (e.g., better artificial limbs), to decrease known risks (e.g., seatbelts in cars), and to meet societal demands (e.g., cell phones). When new technologies become available, they can bring about changes in the way people live and interact with one another. – NRC, 2012

Progression Across Grade Bands

Students began this progression by learning that humans develop technologies to improve our lives. Students should also be aware that all these technologies depend on materials from the natural world, and therefore impact the natural world. In this grade band, students will consider that once a technology exists, engineers continue to improve the technology, including new applications of the technology.

Glass was discussed as a technology that has improved peoples' lives in the section above. In this grade band students should focus on the ways that basic technology improves over time by considering three major reasons for improving technology: increasing benefits, decreasing risks, and meeting societal demands. Tinted glass and more uniform, less wavy glass increase the benefits of glass with better ability to regulate temperature and better visibility. Tempered glass on home and car or windows will break without shattering and leaving many sharp edges. Improvements to technologies are also driven by societal demands. For example, it is possible to apply reflective surfaces to glass to create mirrors.

In earlier grades, students considered that technologies improved our lives. This idea progresses as students also consider that technologies can transform the way that people interact with each other. This can include the way people communicate, but also people's lives in general. For example, prior to the invention of mirrors, people might have only seen their own reflection – the way that others see them - in water, paintings, or polished surfaces.

Current (2018 Implementation): 4.ETS2.3, 5.ETS2.3

4.ETS2.3 - Explain how engineers have improved existing technologies to increase their benefits, to decrease known risks, and to meet societal demands (artificial limbs, seatbelts, cell phones).

<u>Big Ideas:</u>

Advancements in science and technology create opportunities to improve existing technologies.

Scientific Ideas:

- All of the materials that people use to make things in the natural world.
- People apply their understanding of the natural world when they build things.
- The different fields of science help us understand more about the natural world. New discoveries about the world that can lead to new technologies.
- As engineers solve problems in manufacturing and production, new materials and techniques are available and can lead to the development of new technologies.
- There are factors that create demand to improve technologies.
    - Companies improve existing technologies to make more money.
    - Individuals (working alone or in groups) improve technologies to help others.
- People will adopt improved technologies when they understand how the technology can benefit them.

Example(s) of Common Student Ideas:

- The devices and technologies that we use today have not changed since they were invented.

5.ETS2.3 - Identify how scientific discoveries lead to new and improved technologies.

Big Ideas:

Engineers apply scientific knowledge to develop new technologies and tools.

Scientific Ideas:

- People have situations that they want to change or improve. Engineers define problems and develop solutions to address those situations.
- Prototypes are physical models that can be used to test and refine an idea.
- Most technologies are based on technologies that already exist but may be used for a different purpose.
- Scientists make discoveries and engineers apply scientific discoveries in ways that improve existing technologies.

Example(s) of Common Student Ideas:

- Engineers do not need to continue learning science once they begin working.

Revised (2025 Implementation): No Standard

6-8 Standards

By the end of grade 8. All human activity draws on natural resources and has both short- and long-term consequences, positive as well as negative, for the health of both people and the natural environment. The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus, technology use varies from region to region and over time. Technologies that are beneficial for a certain purpose may later be seen to have impacts (e.g., health-related, environmental) that were not foreseen. In such cases, new regulations on the use of new technologies (to mitigate the impacts or eliminate them) may be required. – NRC, 2012

Progression Across Grade Bands:

In earlier grades, students have seen that technologies can benefit people and change the way that people live. Students have also seen that simple technology improves over time as new materials and manufacturing processes emerge.

The idea of scale is an important addition to this progression in middle school. As more people begin to use a technology there will be greater demand for the materials used to make it. Widespread use of any technology means that people in different areas/environments, and with different needs, desires, and values may use the technology. This means that a given technology may be used more in some places than in other places.

People are part of the natural environment. In this instance, the health of people refers to the needs of individuals, such as physical needs and a need for belonging. For individuals, technology can increase food security by providing ways to produce more food using fewer resources, and well as increase an individual's feeling of connectedness. In both examples, there are tradeoffs – food production using fewer resources may rely on synthetic materials that remove resources from natural cycles and overusing devices that connect us remotely to others may limit our interactions and awareness of our immediate connections and surroundings.

Current (2018 Implementation): No Standard

Revised (2025 Implementation): No Standard

Appendix A: K-8 Standards Index

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Grade	Physical Science	Life Science	Earth and Space Science	Engineering, Technology, Applications of Science
Kindergarten	K.PS1.1 (p. 9) K.PS1.2 (p. 10) K.PS1.3 (p. 11)	K.LS1.1 (p. 151) K.LS1.2 (p. 119) K.LS1.3 (p. 167) K.LS3.1 (p. 229)	K.ESS2.1 (p. 353) K.ESS2.2 (p. 354) K.ESS3.1 (p. 378) K.ESS3.2 (p. 386) K.ESS3.3 (p. 393)	K.ETS1.1 (p. 409) K.ETS1.2 (p. 418) K.ETS2.1 (p. 436)
First Grade	1.PS3.1 (p. 72) 1.PS4.1 (p. 101) 1.PS4.2 (p. 102)	1.LS1.1 (p. 119) 1.LS1.2 (p.138) 1.LS1.3 (p. 168) 1.LS2.1 (p. 180) 1.LS2.2 (p. 180) 1.LS2.3 (p. 181)	1.ESS1.1 (p. 299) 1.ESS1.2 (p. 300) 1.ESS1.3 (p. 308)	1.ETS1.1 (p. 409) 1.ETS2.1 (p. 437)
Second Grade	2.PS2.1 (p. 47) 2.PS2.2 (p. 37) 2.PS2.3 (p. 57) 2.PS3.1 (p. 80) 2.PS3.2 (p. 86) 2.PS4.1 (p. 93) 2.PS4.2 (p. 109) 2.PS4.3 (p. 94)	2.LS1.1 (p. 120) 2.LS1.2 (p. 121) 2.LS1.3 (p. 139) 2.LS2.1 2.LS2.2 (p. 206) 2.LS3.1 (p. 242)	2.ESS1.1 (p. 320) 2.ESS2.1 (p. 369) 2.ESS2.2 (p. 327) 2.ESS2.3 (p. 336) 2.ESS2.4 (p. 345)	2.ETS1.1 (p. 410) 2.ETS1.2 (p. 418) 2.ETS1.3 (p. 419) 2.ETS1.4 (p. 428) 2.ETS2.1 (p. 437) 2.ETS2.2 (p. 447)

Grade	Physical Science	Life Science	Earth and Space Science	Engineering, Technology, Applications of Science
Third Grade	3.PS1.1 (p. 13) 3.PS1.2 (p. 24) 3.PS1.3 (p. 15) 3.PS2.1 (p. 49) 3.PS2.2 (p. 50) 3.PS3.1 (p. 74) 3.PS3.2 (p. 75) 3.PS3.3 (p. 82)	3.LS1.1 (p. 123) 3.LS2.1 (p. 221) 3.LS4.1 (p. 280) 3.LS4.2 (p. 281) 3.LS4.3 (p. 290)	3.ESS1.1 (p. 310) 3.ESS2.1 (p. 347) 3.ESS2.2 (p. 356) 3.ESS2.3 (p. 357) 3.ESS2.4 (p. 358) 3.ESS3.1 (p. 388) 3.ESS3.2 (p. 389)	3.ETS1.1 (p. 412) 3.ETS1.2 (p. 430) 3.ETS2.1 (p. 439)
Fourth Grade	4.PS3.1 (p. 64) 4.PS3.2 (p. 88) 4.PS3.3 (p. 89) 4.PS4.1 (p. 96) 4.PS4.2 (p. 104) 4.PS4.3 (p. 112)	4.LS2.1 (p. 184) 4.LS2.2 (p. 184) 4.LS2.3 (p. 185) 4.LS2.4 (p. 186) 4.LS2.5 (p. 208) 4.LS4.1 (p. 256)	4.ESS1.1 (p. 322) 4.ESS1.2 (p. 311) 4.ESS2.1 (p. 329) 4.ESS2.2 (p. 338) 4.ESS2.3 (p. 371) 4.ESS2.4 (p. 330) 4.ESS3.1 (p. 380) 4.ESS3.2 (p. 395)	4.ETS1.1 (p. 431) 4.ETS2.1 (p. 440) 4.ETS2.2 (p. 431) 4.ETS2.3 (p. 449)
Fifth Grade	5.PS1.1 (p. 15) 5.PS1.2 (p. 25) 5.PS1.3 (p. 26) 5.PS1.4 (p. 27) 5.PS2.1 (p. 39) 5.PS2.2 (p. 40) 5.PS2.3 (p. 51) 5.PS2.4 (p. 51) 5.PS2.5 (p. 59)	5.LS1.1 (p. 170) 5.LS3.1 (p. 231) 5.LS3.2 (p. 244) 5.LS4.1 (p. 257) 5.LS4.2 (p. 268)	5.ESS1.1 (p. 302) 5.ESS1.2 (p. 303) 5.ESS1.3 (p. 313) 5.ESS1.4 (p. 314) 5.ESS1.5 (p. 315) 5.ESS1.6 (p. 315) 5.ESS1.7 (p. 323)	5.ETS1.1 (p. 422) 5.ETS1.2 (p. 423) 5.ETS1.3 (p. 424) 5.ETS2.1 (p. 441) 5.ETS2.2 (p. 441) 5.ETS2.3 (p. 450)

Grade	Physical Science	Life Science	Earth and Space Science	Engineering, Technology, Applications of Science
Sixth Grade	6.PS3.1 (p. 66) 6.PS3.2 (p. 77) 6.PS3.3 (p. 68) 6.PS3.4 (p. 69)	6.LS2.1 (p. 189) 6.LS2.2 (p. 189) 6.LS2.3 (p. 199) 6.LS2.4 (p. 211) 6.LS2.5 (p. 212) 6.LS2.6 (p. 213) 6.LS2.7 (p. 223) 6.LS4.1 (p. 292) 6.LS4.2 (p. 293)	6.ESS2.1 (p. 349) 6.ESS2.2 (p. 360) 6.ESS2.3 (p. 362) 6.ESS2.4 (p. 374) 6.ESS2.5 (p. 364) 6.ESS2.6 (p. 365) 6.ESS3.1 (p. 382) 6.ESS3.2 (p. 383) 6.ESS3.3 (p. 397)	6.ETS1.1 (p. 414) 6.ETS1.2 (p. 425)
Seventh Grade	7.PS1.1 (p. 18) 7.PS1.2 (p. 19) 7.PS1.3 (p. 20) 7.PS1.4 (p. 28) 7.PS1.5 (p. 29) 7.PS1.6 (p. 20)	7.LS1.1 (p. 126) 7.LS1.2 (p. 127) 7.LS1.3 (p. 128) 7.LS1.4 (p. 128) 7.LS1.5 (p. 129) 7.LS1.6 (p. 142) 7.LS1.7 (p. 143) 7.LS1.8 (p. 144) 7.LS1.9 (p. 156) 7.LS2.1 (p. 200) 7.LS3.1 (p. 247) 7.LS3.2 (p. 247) 7.LS3.3 (p. 234)	7.ESS3.1 (p. 403) 7.ESS3.2 (p. 404)	7.ETS2.1 (p. 443)

Eighth Grade	8.PS2.1 (p. 53) 8.PS2.2 (p. 54) 8.PS2.3 (p. 42) 8.PS2.4 (p. 43) 8.PS2.5 (p. 44) 8.PS4.1 (p. 98) 8.PS4.2 (p. 106) 8.PS4.3 (p. 114)	8.LS4.1 (p. 259) 8.LS4.2 (p. 260) 8.LS4.3 (p. 271) 8.LS4.4 (p. 271) 8.LS4.5 (p. 272)	8.ESS1.1 (p. 305) 8.ESS1.2 (p. 317) 8.ESS2.1 (p. 375) 8.ESS2.2 (p. 332) 8.ESS2.3 (p. 333) 8.ESS2.4 (p. 340) 8.ESS2.5 (p. 341) 8.ESS3.1 (p. 384) 8.ESS3.2 (p. 390)	8.ETS1.1 (p. 433) 8.ETS1.2 (p. 444)

Biology 1 Standards Index

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Disciplinary Core Idea	**LS1**	**LS2**	**LS3**	**LS4**
Biology 1	Bio1.LS1.1 (p. 132) Bio1.LS1.2 (p. 134) Bio1.LS1.3 (p. 147) Bio1.LS1.4 (p. 159) Bio1.LS1.5 (p. 160) Bio1.LS1.6 (p. 162) Bio1.LS1.7 (p. 175)	Bio1.LS2.1 (p. 192) Bio1.LS2.2 (p. 202) Bio1.LS2.3 (p. 216) Bio1.LS2.4 (p. 217) Bio1.LS2.5 (p. 225)	Bio1.LS3.1 (p. 237) Bio1.LS3.2 (p. 238) Bio1.LS3.3 (p. 250) Bio1.LS3.4 (p. 251)	Bio1.LS4.1 (p. 262) Bio1.LS4.2 (p. 274) Bio1.LS4.3 (p. 285) Bio1.LS4.4 (p. 286) Bio1.LS4.5 (p. 296)

Appendix B: Standards By Component Idea

Discipline: Physical Sciences

Disciplinary Core Idea 1: Matter and Its Interactions

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Structure and Properties of Matter	K.PS1.1, K.PS1.2, K.PS1.3	3.PS1.1, 3.PS1.3, *5.PS1.1*, 5.PS1.2	*7.PS1.1*, 7.PS1.2, 7.PS1.3, 7.PS1.6
B. Chemical Reactions	*No Standard*	3.PS1.2, 5.PS1.3, 5.PS1.4	7.PS1.4, 7.PS1.5
C. Nuclear Processes	*No content*	*No content*	*No standard*

Disciplinary Core Idea 2: Motion and Stability: Forces and Interactions

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Forces and Motion	2.PS2.1, 2.PS2.2	5.PS2.1, 5.PS2.2	8.PS2.3, 8.PS2.4, 8.PS2.5
B. Types of Interactions	*2.PS2.1*	3.PS2.1, 3.PS2.2, 5.PS2.3, 5.PS2.4	8.PS2.1, 8.PS2.2
C. Stability and Instability in Physical Systems	2.PS2.3	5.PS2.5	*No standard*

Disciplinary Core Idea 3: Energy

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Definitions of Energy	*No content*	4.PS3.1	6.PS3.1, 6.PS3.3, 6.PS3.4
B. Conservation of Energy and Energy Transfer	1.PS3.1	3.PS3.1, 3.PS3.2	6.PS3.2
C. Relationship Between Energy and Forces	2.PS3.1	3.PS3.3	*No standard*
D. Energy in Chemical Processes and Everyday Life	2.PS3.2	4.PS3.2, 4.PS3.3	*No standard*

Disciplinary Core Idea 4: Waves and Their Applications in Technologies for Information Transfer

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Wave Properties	2.PS4.1, 2.PS4.3	4.PS4.1	8.PS4.1
B. Electromagnetic Radiation	1.PS4.1, 1.PS4.2	4.PS4.2	8.PS4.2
C. Information Technologies and Instrumentation	2.PS4.2	4.PS4.3	8.PS4.3

Discipline: Life Sciences

Disciplinary Core Idea 1: From Molecules to Organisms: Structures and Processes

Component Idea	K–2 Standards (2018)	3–5 Standards (2018)	6–8 Standards (2018)	9-12 Standards (2025)
A. Structure and Function	*K.LS1.2*, 1.LS1.1, 2.LS1.1, *2.LS1.2*	3.LS1.1	7.LS1.1, *7.LS1.2*, 7.LS1.3, 7.LS1.4, 7.LS1.5	Bio1.LS1.1, Bio1.LS1.2
B. Growth and Development of Organisms	1.LS1.2, 2.LS1.3	*No standard*	7.LS1.6, 7.LS1.7, *7.LS1.8*	Bio1.LS1.3
C. Organization for Matter and Energy Flow in Organisms	K.LS1.1	*No standard*	7.LS1.9	Bio1.LS1.4, Bio1.LS1.5, Bio1.LS1.6
D. Information Processing	K.LS1.3, 1.LS1.3	5.LS1.1	*No standard*	Bio1.LS1.7,

Disciplinary Core Idea 2: Ecosystems: Interactions, Energy, and Dynamics

Component Idea	K–2 Standards (2018)	3–5 Standards (2018)	6–8 Standards (2018)	9-12 Standards (2025)
A. Interdependent relationships in ecosystems	1.LS2.1, 1.LS2.2, 1.LS2.3, 2.LS2.1	4.LS2.2, 4.LS2.3, 4.LS2.4	6.LS2.1, 6.LS2.2	Bio1.LS2.1
B. Cycles of Matter and Energy Transfer in Ecosystems	*No standard*	4.LS2.1	6.LS2.3, 7.LS2.1	Bio1.LS2.2
C. Ecosystem Dynamics, Functioning and Resilience	2.LS2.2	4.LS2.5	6.LS2.4, 6.LS2.5, 6.LS2.6	Bio1.LS2.3, Bio1.LS2.4
D. Social Interactions and Group Behavior	*No standard*	3.LS2.1	6.LS2.7	Bio1.LS2.5

Disciplinary Core Idea 3: Heredity: Inheritance and Variation of Traits

Component Idea	K–2 Standards (2018)	3–5 Standards (2018)	6–8 Standards (2018)	9-12 Standards (2025)
A. Inheritance of Traits	K.LS3.1	5.LS3.1	7.LS3.3	Bio1.LS3.1, Bio1.LS3.2
B. Variation of Traits	2.LS3.1	5.LS3.2	7.LS3.1, 7.LS3.2	Bio1.LS3.3 Bio1.LS3.4

Disciplinary Core Idea 4: Biological Change: Unity and Diversity

Component Idea	K–2 Standards (2018)	3–5 Standards (2018)	6–8 Standards (2018)	9-12 Standards (2025)
A. Evidence of Common Ancestry and Diversity	*No standard*	4.LS4.1, 5.LS4.1	8.LS4.1, 8.LS4.2	Bio1.LS4.1
B. Natural Selection	*No content*	5.LS4.2	8.LS4.3, 8.LS4.4, 8.LS4.5	Bio1.LS4.2
C. Adaptation	*No standard*	3.LS4.1, 3.LS4.2	No standard	Bio1.LS4.3, Bio1.LS4.4
D. Biodiversity and Humans	*No standard*	3.LS4.3	6.LS4.1, 6.LS4.2	Bio1.LS4.5

Discipline: Earth and Space Sciences

Disciplinary Core Idea 1: The Earth's Place in the Universe

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. The Universe and Its Stars	1.ESS1.1, 1.ESS1.2	5.ESS1.1, 5.ESS1.2	8.ESS1.1
B. Earth and the Solar System	1.ESS1.3	3.ESS1.1, 4.ESS1.2, 5.ESS1.3, 5.ESS1.4, 5.ESS1.5, 5.ESS1.6	8.ESS1.2
C. The History of Planet Earth	2.ESS1.1	4.ESS1.1, 5.ESS1.7	*No standard*

Disciplinary Core Idea 2: Earth's Systems

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Earth's Materials and Systems	2.ESS2.2	4.ESS2.1, 4.ESS2.4	8.ESS2.3, 8.ESS2.4
B. Plate Tectonics and Large-Scale System Interactions	2.ESS2.3	4.ESS2.2	8.ESS2.2, 8.ESS2.5
C. The Roles of Water in Earth's Surface Processes	2.ESS2.4	3.ESS2.1	6.ESS2.1
D. Weather and Climate	K.ESS2.1, K.ESS2.2	3.ESS2.2, 3.ESS2.3, 3.ESS2.4	6.ESS2.2, 6.ESS2.3, 6.ESS2.5, 6.ESS2.6
E. Biogeology	2.ESS2.1	4.ESS2.3	6.ESS2.4, 8.ESS2.1

Disciplinary Core Idea 3: Earth and Human Activity

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Natural Resources	K.ESS3.1	4.ESS3.1	6.ESS3.1, 6.ESS3.2, 8.ESS3.1
B. Natural Hazards	K.ESS3.2	3.ESS3.1, 3.ESS3.2	8.ESS3.2
C. Human Impacts on Earths Systems	K.ESS3.3	4.ESS3.2	6.ESS3.3
D. Global Climate Change	*No content*	*No standard*	7.ESS3.1, 7.ESS3.2

Discipline: Engineering, Technology, and Applications of Science

Disciplinary Core Idea 1: Engineering Design

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Defining and Delimiting and Engineering Problem	K.ETS1.1, 1.ETS1.1, 2.ETS1.1	3.ETS1.1	6.ETS1.1, 8.ETS1.2
B. Developing Possible Solutions	K.ETS1.2, 2.ETS1.2, 2.ETS1.3	3.ETS1.2, 5.ETS1.1, 5.ETS1.2, 5.ETS1.3	*No standard*
C. Optimizing the Design Solution	2.ETS1.4	4.ETS1.1, 4.ETS2.1	6.ETS1.2, 8.ETS1.1

Disciplinary Core Idea 2: Links Among Engineering, Technology, Science, and Society

Component Idea	K–2 Standards	3–5 Standards	6–8 Standards
A. Interdependence of Science, Engineering, and Technology	K.ETS2.1, 1.ETS2.1, 2.ETS2.2	3.ETS2.1, 4.ETS2.1, 5.ETS2.1, 5.ETS2.2	7.ETS2.1
B. Influence of Engineering, Technology, and Science on Society and the Natural World	2.ETS2.2	4.ETS2.3, 5.ETS2.3	*No standard*