Science Curriculum

Research Methods in Earth Science
2.5 Credits
Course Description

The half year Earth science course is designed to interpret and understand the world around you. In order to do so, students will investigate and study the interactions between the four major Earth’s spheres, including the geosphere, atmosphere, hydrosphere and biosphere in order to explain Earth’s formation, processes, history, landscapes, how and why Earth changes over time. The course will also explore how current actions of man interact and affect Earth’s spheres leading to local and global changes. Topics to be addressed include, but are not limited to, mapping Earth’s surface, minerals, rocks, plate tectonics, earthquakes, volcanoes, geologic time, and meteorology. Students will participate in laboratory exercises, small group activities, web based investigations, class discussions, projects, and research.

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<th>Unit</th>
<th>Topic</th>
<th>Duration</th>
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<td>Unit 1</td>
<td>Physics of the Earth Systems</td>
<td>5 weeks</td>
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<td>Unit 2</td>
<td>Dynamic Earth</td>
<td>5 weeks</td>
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<td>Unit 3</td>
<td>Human Activity and Energy</td>
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<td>Review</td>
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# Physics of the Earth Systems

## Unit Summary

**How much force and energy is needed to move a continent?**

Students investigate the energy within the Earth as it drives Earth’s surface processes. Students *evaluate evidence* of the past and current movements of continental and oceanic crust for theory of plate tectonics to explain the ages of crustal rocks. Finally, students *develop a model based on evidence* of the Earth’s interior to describe the cycle of matter by thermal convection. The crosscutting concepts of *patterns and stability, cause and effect, stability and change, energy and matter*, and *systems and systems models* are called out as organizing concepts for these disciplinary core ideas.

Within this unit, connections to Physical Science Performance Expectations are made. Students *plan and conduct investigations*, and *analyze data and using math to support claims* in order to develop an understanding of ideas related to why some objects keep moving and some objects fall to the ground. Students will also build an understanding of forces and Newton’s second law. They will develop an understanding that the total momentum of a system of objects is conserved when there is no net force on the system. Students use mathematical representations to support a claim regarding the relationship among frequency, wavelength, and speed of waves traveling in various media, such as the Earth’s layers. Students then apply their understanding of how magnets are created to model the generation of the Earth’s magnetic field. The crosscutting concept of *cause and effect* is called out as an organizing theme. Students are expected to demonstrate proficiency in *planning and conducting investigations and developing and using models*. These fundamental physics concepts provide a foundation for understanding the dynamics of Earth motions and processes over deep time.

This unit is based on HS-ESS1-5, HS-ESS2-1, and HS-ESS2-3, HS-PS2-5 (secondary to HS-ESS2-3), and HS-PS4-1 (secondary to HS-ESS2-3). HS-PS2-1 may also be integrated in this unit.

*[Note: The disciplinary core ideas, science and engineering practices, and crosscutting concepts can be taught in either this course or in a high school physics course.]*

## Student Learning Objectives

**Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.** *Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of*
<table>
<thead>
<tr>
<th>North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).</th>
<th>(HS-ESS1-5)</th>
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<tbody>
<tr>
<td>(Secondary to HS-ESS1-5) Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.</td>
<td>(HS-PS2-1)</td>
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<tr>
<td>[Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]</td>
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<tr>
<td>Develop a model to illustrate how Earth’s internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.</td>
<td>(HS-ESS2-1)</td>
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<tr>
<td>[Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth’s surface.]</td>
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<tr>
<td>Develop a model based on evidence of Earth’s interior to describe the cycling of matter by thermal convection.</td>
<td>(HS-ESS2-3)</td>
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<td>[Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth’s three dimensional structure obtained from seismic waves, records of the rate of change of Earth’s magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth’s layers from high-pressure laboratory experiments.]</td>
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<tr>
<td>(Secondary to HS-ESS2-3) Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.</td>
<td>(HS-PS2-5)</td>
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<tr>
<td>[Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]</td>
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<tr>
<td>(Secondary to HS-ESS2-3) Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.</td>
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<tr>
<td>[Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.]</td>
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**Storyline:** Earth and many planets have various landforms, which make them unique. Plate tectonics, continental drift, and movement of rock and minerals can explain the landforms here on Earth. Can plate tectonics explain landforms and features on other planets?

**Part A: Essential Question:** How long does it take to make a mountain?

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Formative Assessment</th>
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<tr>
<td>• Earth’s systems, which are dynamic and interact, cause feedback effects that can increase or decrease the original changes.</td>
<td><strong>Students who understand the concepts are able to:</strong></td>
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<tr>
<td>• 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 geologic history.</td>
<td>• Develop a model to illustrate how Earth’s internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.</td>
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<td>• Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth’s crust.</td>
<td>• Develop a model to illustrate how the appearance of land features and sea-floor features are a result of both constructive forces and destructive mechanisms.</td>
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<td>• Change and rates of change can be quantified and modeled over very short or very long periods of time.</td>
<td>• Quantify and model rates of change of Earth’s internal and surface processes over very short and very long periods of time.</td>
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<td>• Some system changes are irreversible.</td>
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<th>Overarching Questions</th>
<th>Sample Activities</th>
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<td>Gather evidence to support the claim that plate tectonics explains the past and current drift</td>
<td>Can you defend continental drift?</td>
<td><strong>Plate Tectonics (a)</strong> Students are put into the role of</td>
<td><strong>Plate tectonics (ptintroa)(word doc) (45-90 min)</strong></td>
</tr>
<tr>
<td>movements of the rocks at Earth’s surface and provides a framework for understanding its geologic history. (ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5),(HS-ESS2-1)</td>
<td>Alfred Wegener, while they claim and defend their position on continental drift.</td>
<td><em>Research needs to be conducted, computer or library use a plus.</em></td>
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| Gather evidence to refute the claim that plate tectonics explains the past and current movements of the rocks at Earth’s surface and provides a framework for understanding its geologic history. (ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5),(HS-ESS2-1) | Why support the theory of continental drift? | **Plate Tectonics (b)**  
Students will play the role of conference goers, and deny the claims set forth by Wegener, by providing supporting evidence.  
Plate tectonics (ptintro)(word doc) (45-90 min)  
*Research needs to be conducted, computer or library use a plus.* |
| Model how plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth’s crust. (ESS2.B Grade 8 GBE) (HS-ESS2-1) | How can you explain the formation or deformation of Earth’s crust? | **Stressful Situations**  
Students will use food items to gain an understanding of the major events taking place at the surface, or within the Earth that have deformational effects on the crust.  
Stress (word) (45 min) |
| Evaluate a claim regarding | Are plate tectonics responsible | **Extra-terrestrial Plate Tectonics** Extraterrestrial Plate Tectonics |
whether plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth’s crust. (ESS2.B Grade 8 GBE) (HS-ESS2-1)

| for the landforms on other planets? | Students must research and decide whether plate tectonics is operating on another planet in our solar system. |
| (word) (varied 180-270) |

**Storyline:** A classmate states that continental drift could not be possible because it would take far too much force to move tectonic plates. Describe the hypotheses scientists use to explain the movement of tectonic plates. What hypothesis do many scientists think may explain the great force needed to move plates?

**Part B: Essential Question:** How much force is needed to move a continent? What can possibly provide the energy for that much force?

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| • Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth’s surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust.  
• Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth’s interior and gravitational movement of denser materials toward the interior.  
• The radioactive decay of unstable isotopes continually |
| Students who understand the concepts are able to:  
• Develop an evidence-based model of Earth’s interior to describe the cycling of matter by thermal convection.  
• Develop a one-dimensional model, based on evidence, of Earth with radial layers determined by density to describe the cycling of matter by thermal convection.  
• Develop a three-dimensional model of Earth’s interior, based on evidence, to show mantle convection and the resulting plate tectonics.  
• Develop a model of Earth’s interior, based on evidence, to show |
generates new energy within Earth’s crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

- Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet.
- Energy drives the cycling of matter within and between Earth’s systems.
- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.
- Science knowledge is based on empirical evidence.
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.
- Science includes the process of coordinating patterns of evidence with current theory.

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| Develop a model to explain how the evidence of magnetic field changes in rocks on the ocean floor provide evidence of sea floor | How do materials move within and throughout various Earth systems? | **Dynamic Earth** Students will investigate and explore how sea floor spreading, creates new rock, while affecting the magnetic field of the rock on | *Sea-Floor Spreading (word)* (90 min)  
*Seafloor1&Seafloor2 (pdf)* (45 min) |
Analyze data to develop a model that demonstrates the epicenter of an earthquake. (HS-ESS2-3)

Find an epicenter.

Can you determine the location of an earthquake?

Finding Epicenters

Students will use data sets of past earthquake activity, to determine the epicenter of that earthquake.

Finding Epicenters (pdf) (45 min)

Create a model to explain how temperature and density changes in Earth’s interior can lead to movement of Earth’s layers. (HS-ESS2-3)

Convection in the Earth

Students will use the inquiry process to identify temperature as a condition that can change the density of a substance and affect movement.

Convection in the Earth

Av-Geolesson (pdf)(180 min)

Storyline: The world is 4.5 billion years old, which is determined by the decay chain of uranium-238. If this is true, why do rocks have different ages? Shouldn't all rocks have about the same age?

Part C: Essential Question: Are all rocks the same age?

Concepts

• Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.

Formative Assessment

Students who understand the concepts are able to:

• Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics
- Plate tectonics theory explains the past and current movements of the rocks at Earth’s surface and provides a framework for understanding its geologic history.
- Spontaneous radioactive decay follows a characteristic exponential decay law.
- Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.
- Empirical evidence is needed to identify patterns in crustal rocks.

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| Create a model to explain radioactive decay. (HS-ESS2-3) | How is radioactive decay used to date fossils or artifacts? | **Half-Life of Paper, M&M’s, Pennies, Puzzle Pieces, & Licorice**
Students try to model radioactive decay by using the scientific thought process of creating a hypothesis, then testing it through inference. | [Half_Life_ALL (pdf)](45-90 mins) |
| Use a model to predict the decay of nuclei. (HS-ESS2-3) | What happens when a nucleus decays? | **Radioactive Decay**
Students will make predictions, using a model to demonstrate understanding when nuclei decay. | [Radioactive_Decay (pdf)](45 min) |
Interdisciplinary Connections

**English Language Arts/Literacy**

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of Earth's internal and surface processes and the different spatial and temporal scales at which they operate and to add interest.

- Cite specific textual evidence to support analysis of the Earth's interior, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to model the Earth's interior and the cycling of matter by thermal convection to enhance understanding of findings, reasoning, and evidence and to add interest.

- Cite specific textual evidence of past and current movements of continental and oceanic crust to support analysis of the ages of crustal rocks, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- Evaluate the hypotheses, data, analysis, and conclusions regarding the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

- Write informative texts about the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, including the narration of historical events, scientific procedures/experiments, or technical processes.

**Mathematics**

- Represent symbolically an explanation for Earth's internal and surface processes and the different spatial and temporal scales at which they operate, and manipulate the representing symbols. Make sense of quantities and relationships about Earth's internal and surface processes and the different spatial and temporal scales at which they operate symbolically, and manipulate the representing symbols.

- Use a mathematical model to explain Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Identify important quantities in Earth's internal and surface processes and the different spatial and temporal scales at
which they operate and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

- Use units as a way to understand problems and to guide the solution to multistep problems representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Choose and interpret units consistently in formulas representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate; choose and interpret the scale and the origin in graphs and data displays representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate.

- Define appropriate quantities for the purpose of descriptive modeling of Earth's internal and surface processes and the different spatial and temporal scales at which they operate.

- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate.

- Represent an explanation for the Earth's interior and the cycling of matter by thermal convection symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the Earth's interior and the cycling of matter by thermal convection symbolically and manipulate the representing symbols.

- Use a mathematical model to explain the Earth's interior and the cycling of matter by thermal convection. Identify important quantities in the Earth's interior and the cycling of matter by thermal convection and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

- Use units as a way to understand problems and to guide the solution of multistep problems about the Earth's interior and the cycling of matter by thermal convection; choose and interpret units consistently in formulas representing the Earth's interior and the cycling of matter by thermal convection; choose and interpret the scale and the origin in graphs and data displays of the Earth's interior and the cycling of matter by thermal convection.

- Use units as a way to understand problems and to guide the solution of multistep problems about the ages of crustal rocks and past and current movements of continental oceanic crust; choose and interpret units consistently in formulas representing the ages of crustal rocks and past and current movements of continental and oceanic crust; choose and interpret the scale and the origin in
graphs and data displays of the ages of crustal rocks and past and current movements of continental and oceanic crust.

- Define appropriate quantities for the purpose of descriptive modeling of the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities related to the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust.
- Represent symbolically an explanation for the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, and manipulate the representing symbols. Make sense of quantities and relationships about the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust symbolically and manipulate the representing symbols.

Research on Student Learning

Students of all ages may hold the view that the world was always as it is now, or that any changes that have occurred must have been sudden and comprehensive. The students in these studies did not, however, have any formal instruction on the topics investigated. Moreover, middle-school students taught by traditional means are not able to construct coherent explanations about the causes of volcanoes and earthquakes.

High-school students also have difficulty in conceptualizing gravitational forces as interactions between two objects. In particular, they have difficulty in understanding that the magnitudes of the gravitational forces that two objects of different mass exert on each other are equal therefore resulting in a deeper understanding of the relationships between the object as per of measurable phenomenon. The difficulties persist even after specially designed instruction (NSDL, 2015).

Prior Learning

Physical science

- Substances are made from 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.
• 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 others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may 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.

• 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.

• 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—e.g., Earth and the sun.

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

• 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.

• 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.
• When the motion energy of an object changes, there is inevitably some other change in energy at the same time.

• 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 spontaneously transferred out of hotter regions or objects and into colder ones.

• 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.

• 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.

• A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.

• However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

Life science

• Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant 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.

Earth and space science

• The geologic time scale interpreted from rock strata provides a way to organize Earth’s history. Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale.

• All Earth processes are the result of energy flowing and matter cycling within and among the planet’s systems. This energy is derived
The energy that flows 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.
- 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.
- 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.

### Connections to Other Courses

**Physical science**

- Newton’s law of universal gravitation and Coulomb’s law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
• Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
• Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
• Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
• The availability of energy limits what can occur in any system.
• Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
• When two objects interacting through a field change relative position, the energy stored in the field is changed.
• Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
• The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.
• 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.

Earth and space science

• Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
• Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth’s surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust.
• Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth’s interior and gravitational movement of denser materials toward the interior.
The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun’s energy output or Earth’s orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.

The radioactive decay of unstable isotopes continually generates new energy within Earth’s crust and mantle, providing the primary source of the heat that drives mantle convection.

Plate tectonics can be viewed as the surface expression of mantle convection.

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 geologic 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.

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**Unit Project/ Lab Performance/ Assessments**

**EarthViewer (IPAd or Android)** or for Chrome browsers: Students explore the co-evolution of the geology and biology found on Earth to develop arguments from evidence for the co-evolution of geology and biology found on Earth. If IPads, Androids or Chrome browsers are not available, similar interactives may be found at this link, and this link.

**Le Pichon’s 1968 seafloor age data**: Students map and analyze LePichon's field data to identify patterns in the ages of the ocean floor. Extensions: Additional maps and data may be found at NOAA Marine Geology and Geophysics and from their image site. An associated research paper may be found here.


**IRIS - Measuring the Rate of Plate Motion**: Students compare GPS data of plate motion to determine the rate at which tectonic plates move. Alternatively, students use real-time plate motion data from UNAVCO to determine the rate at which plates move.

**IODP: Deep Earth Academy Core Data investigations**: Students investigate seafloor core data to evaluate multiple lines of evidence to support the dynamic plate theory.
GeoMapApp and GeoMapApp educational activities: Students visualize and explore various lines of evidence for plate dynamics and evaluate the strengths of each line of evidence in supporting the dynamic plate theory.

Lithosphere age research paper: Students read this article which describes how seismic data is used to determine the age of the crust, and the inherent issues associated with the procedure. They use this information in their analysis, evaluation, and synthesis of evidence for the dynamic plate theory.


Google Earth Age of the Lithosphere: Students compare the age of the seafloor and continental crust using the data at this site, or USGS data found here or found here.

Geologic time and rates of landscape evolution: Students model rates of landscape evolution to gain an understanding of change over deep, historical, and recent time. Alternatively, students compare rates of erosion of a mountain landscape to agricultural lands by completing this activity.

Hotspot Lesson: Students analyze the rate of movement of the Hawaiian Island chain to further understand rates of change in geologic processes.

How Erosion Builds Mountains: by Mark Brandon and Nicholas Pinter, from Scientific American. Students read this article and identify feedbacks in the mountain building process. To support their model, they gather supporting evidence using this isostasy model.

Comparing models of the Earth’s interior from data: Students compare two models of the Earth’s interior and argue from evidence which model more strongly supports the evidence. Seismic Wave: Students receive additional practice in the interpretation of seismic data to model the interior of the Earth.

<table>
<thead>
<tr>
<th>Embedded English Language Arts/Literacy</th>
<th>Mathematics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS2-1), (HS-ESS1-5), (HS-ESS2-3) <strong>RST.11-12.1</strong></td>
<td>Reason abstractly and quantitatively. (HS-PS2-1), (HS-PS4-1), (HS-ESS1-5), (HS-ESS2-1), (HS-ESS2-3) <strong>MP.2</strong></td>
</tr>
<tr>
<td>Model with mathematics. (HS-PS2-1), (HS-PS4-1), (HS-ESS2-1), (HS-</td>
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</table>
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS1-5) RST.11-12.8

Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS2-5) WHST.9-12.7

Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS2-5) WHST.11-12.8

Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS2-1), (HS-PS4-1) RST.11-12.7

Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS2-1), (HS-PS2-5), WHST.11-12.9

Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS1-5) WHST.9-12.2

ESS2-3) MP.4

Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-1), (HS-PS2-5), (HS-ESS1-5), (HS-ESS2-1), (HS-ESS2-3) HSN.Q.A.1

Define appropriate quantities for the purpose of descriptive modeling. (HS-PS2-1), (HS-PS2-5), (HS-ESS1-5), (HS-ESS2-1), (HS-ESS2-3) HSN.Q.A.2

Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-1), (HS-PS2-5), (HS-ESS1-5), (HS-ESS2-1), (HS-ESS2-3) HSN.Q.A.3

Interpret expressions that represent a quantity in terms of its context. (HS-PS2-1), (HS-PS2-4), (HS-PS4-1) HSA.SSE.A.1

Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS2-1), (HS-PS4-1) HSA.SSE.B.3

Create equations and inequalities in one variable and use them to solve problems. (HS-PS2-1) HSA.CED.A.1

Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. (HS-PS2-1) HSA.CED.A.2

Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS2-1) (HS-PS4-1) HSA.CED.A.4
Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-ESS2-1), (HS-ESS2-3) **SL.11-12.5**

Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. (HS-PS2-1) **HSF-IF.C.7**

Represent data with plots on the real number line (dot plots, histograms, and box plots). (HS-PS2-1) **HSS-IS.A.1**

<table>
<thead>
<tr>
<th>Vocabulary</th>
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<tr>
<td>Radioactive Decay</td>
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<tr>
<td>Plate Tectonics</td>
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<tr>
<td>Energy</td>
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<td>Seismic Waves</td>
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<td>Continental Drift</td>
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<td>Sea Floor Spreading</td>
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<td>Isotopes</td>
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<td>Earthquake</td>
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<td>Volcanic Eruptions</td>
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<td>Ecological Succession</td>
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<tr>
<th>Suggested Field Trips</th>
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<tbody>
<tr>
<td>Liberty Science Center, NJ State Museum (Trenton), AMNH, Paterson Great Falls, Garrett Mountain Reservation, Sterling Hills Mine</td>
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</table>

**Unit 2: Dynamic Earth Systems**

**Unit Summary**

*How can one explain and predict interactions between Earth materials and within Earth systems?*

In this unit of study, planning and carrying out investigations, analyzing and interpreting data, developing and using models, and engaging in arguments from evidence are key practices to explore the dynamic nature of Earth systems. Students apply these practices to illustrate how Earth’s interacting systems cause feedback effects on other Earth systems, to investigate the properties of water and its effects on Earth materials and surface processes, and to model the cycling of carbon through all of the Earth’s spheres. Students seek evidence to construct arguments about the simultaneous co-evolution of the Earth’s systems and life on Earth. The crosscutting concepts of energy and matter, structure and function, and stability and change are called out as organizing concepts for these disciplinary core...
This unit is based on HS-ESS2-2, HS-ESS2-5, HS-ESS2-6, and HS-ESS2-7. [Note: The disciplinary core ideas, science and engineering practices, and crosscutting concepts can be taught in either this course or in a high school chemistry course.]

<table>
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<tr>
<th>Student Learning Objectives</th>
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**Analyze geoscience data to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.** [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth’s surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.] (HS-ESS2-2)

**Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).] (HS-ESS2-5)

**Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.** [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.] (HS-ESS2-6)

**Construct an argument based on evidence about the simultaneous co-evolution of Earth’s systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth’s other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth’s surface. Examples of include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of}
animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth’s other systems.] (HS-ESS2-7)

Storyline: Earth is a complex system of interacting systems. How do major systems affect and interact with each other?

**Part A: How do changes in the geosphere affect the atmosphere?**

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Formative Assessment</th>
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</table>
| • Earth’s systems, which are dynamic and interact, cause feedback effects that can increase or decrease the original changes.  
• The foundation for Earth’s global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy’s re-radiation into space.  
• Feedback (negative or positive) can stabilize or destabilize a system. | **Students who understand the concepts are able to:**  
• Analyze geoscience data using tools, technologies, and/or models (e.g., computational, mathematical) to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems. |
<table>
<thead>
<tr>
<th>Learning Objective and Standard</th>
<th>Overarching Questions</th>
<th>Sample Activities</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop a model that mimics atmospheric layers as they are affected by the Greenhouse Effect. (HS-ESS2-2)</td>
<td>How does infrared radiation causes changes to Earth’s atmosphere?</td>
<td>What is a Model? Students can explain how a model works. Students can describe the effect of atmosphere on Earth’s surface temperature and describe variation of temperature with altitude.</td>
<td>What is a Model (pdf) (90 mins)</td>
</tr>
<tr>
<td>Gather evidence o support a claim regarding how climate has an effect on animal behavior. (HS-</td>
<td>What are factors that affect animal behavior? What are factors that affect</td>
<td>Lab #13 Argument Driven Inquiry p. 179-191(approx. 180-250 min) (see Resource folder)</td>
<td>(Additional Resources)</td>
</tr>
<tr>
<td>Lab #13</td>
<td>Environmental Influences on Animal Behavior: How has climate change</td>
<td><strong>MY NASA DATA</strong>: Students select satellite datasets to answer questions related to system interactions and feedbacks.</td>
<td></td>
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<td></td>
<td></td>
<td><strong>Images of Change</strong>: Students explore these images of the impacts of climate change</td>
<td></td>
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</table>
Analyze how an increase in temperature affects the overall climate. (HS-ESS2-2)

What is climate?
When Will the Artic Ice Cap Disappear? Activity

Northwestern University Climate Curriculum p. 1-11(approx. 80 min.) (see Resource folder)
https://osep.northwestern.edu/sites/default/files/Arctic%20Ice%20Data_ALL.pdf

Additional Resources

MY NASA DATA: Students select satellite datasets to answer questions related to system interactions and feedbacks.

**Storyline:** Water changes forms over and over again. This never-ending cycle brings color and life to the Earth. Looking at the Earth from space, you see the beautiful blue color of its oceans. Every living thing on Earth depends on water to live. Plants, animals, and people all need water. What properties in water allow it to be such a force in shaping our planet?

**Part B: How do the properties and movements of water shape Earth's surface and affect its systems?**

<table>
<thead>
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</table>
| - The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics.  
- The properties include water's exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing, dissolve and transport | Students who understand the concepts are able to:  
- Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. |
- materials; and lower the viscosities and melting points of rocks.

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</table>
| Develop a model to explain how thermal expansion impacts sea level. (HS-ESS2-5) | How does thermal expansion of seawater impact sea level? | Thermal Expansion of Sea Water  
Students will be able to describe the change in volume when water is exposed to heat.  
Students will learn that thermal expansion of seawater is one of the causes of sea level rise due to climate change. | Thermal Expansion of Sea Water (pdf)(45 min) |
| How does water absorb and transfer energy in the Earth system? (HS-ESS2-5) | What is the importance of convection in heating and cooling? | Density, Buoyancy, and Convection  
Students observe and report the process of convection and will learn concepts of density, buoyancy, thermal expansion and contraction, and convection. | Density, Buoyancy, and Convection (pdf) (180-220 mins) |
| Investigate the properties of water. (HS-ESS2-5) | What are physical properties of water?  
What are the chemical properties of water? | The Science of Water Lab  
Lab #14 Interdependence of Organisms: Why is the Sport Fish | The Science of Water Lab (approx. 40-80 minutes) (see Resource folder)  
**Population of Lake Grace Decreasing in Size?**


Lab #14 Scientific Argumentation in Biology pg. 192-209 (approx. 160-200 min.)

(Additional Resources)

**Images of Change:** Students explore these images of the impacts of climate change over time to develop explanations from evidence of how an impact in one component of the Earth system has effects in other components of the Earth system.

**USGS Realtime Water data** and **Climate data:** Students create and run an investigation to determine the relationship between stream flow and precipitation data, or another parameter.

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**Storyline:** The biogeochemical cycle in which carbon is exchanged between Earth’s terrestrial biosphere, hydrosphere, geosphere, and atmosphere is called the carbon cycle. The global carbon budget is the balance of the fluxes of carbon between these four reservoirs. How does the carbon cycle influence change in other Earth systems?

**Part C:** How does carbon cycle among the hydrosphere, atmosphere, geosphere, and biosphere?

<table>
<thead>
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<tbody>
<tr>
<td>• Gradual atmospheric changes were due to plants and other</td>
<td>Students who understand the concepts are able to:</td>
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</table>
organisms that captured carbon dioxide and released oxygen.

- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- The total amount of energy and matter in closed systems is conserved.
- The total amount of carbon cycling among and between the hydrosphere, atmosphere, geosphere, and biosphere is conserved.

- Develop a model based on evidence to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- Develop a model based on evidence to illustrate the biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere, providing the foundation for living organisms.

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<tbody>
<tr>
<td>Analyze data to predict patterns of gas movement. (HS-ESS2-6),(HS-ESS2-7)</td>
<td>How does carbon dioxide vary through the atmosphere at different latitudes, altitudes, and at different times of the year?</td>
<td><strong>Studying CO₂ from Pole to Pole</strong>&lt;br&gt;Students will analyze scientific data and predict patterns of gas movement in various situations.&lt;br&gt;Students will understand that the data sets they are analyzing come from field research and how to incorporate that research into their own projects.</td>
<td><strong>Studying CO₂ from Pole to Pole (pdf)(135 mins)</strong></td>
</tr>
<tr>
<td>Analyze the effect of increased CO₂ in the environment. (HS-</td>
<td>What is the greenhouse effect? What gases are considered</td>
<td><strong>Carbon Capture and Sequestration</strong></td>
<td><strong>Carbon Capture and Sequestration (approx. 150-250</strong></td>
</tr>
</tbody>
</table>
| ESS2-6), (HS-ESS2-7) | greenhouse gases?  
What are the sinks and sources of CO₂? | Capturing Carbon: Where Do We Put It and Why? (approx. 40-80 min.) (see Resource folder)  
https://osep.northwestern.edu/sites/default/files/ClimateChange/CO2WhatAGas.pdf |
|---|---|---|
|  |  | Capturing Carbon: Where Do We Put It and Why? (approx. 40-80 min.) (see Resource folder)  
https://osep.northwestern.edu/sites/default/files/ClimateChange/CO2WhatAGas.pdf |
|  | (Additional Resources)  
Climate Reanalyzer: Students use the Environmental Change Model of the Climate Reanalyzer to study the feedbacks in the climate system.  
Greenhouse Effect: Students explore the atmosphere during the ice age and today. What happens when you add clouds? Change the greenhouse gas concentration and see how the temperature changes. Then compare to the effect of glass panes. Zoom in and see how light interacts with molecules. Do all |
| Provide evidence to support a claim regarding the relationship between CO\(_2\) and temperature in Earth’s oceans and subsequent effects on sea level. (HS-ESS2-6),(HS-ESS2-7) | How does an increase in temperature affect nearby ecosystems? | Exploring the Relationship between CO\(_2\) and Temperature using Brassica Plants. | Exploring the Relationship between CO\(_2\) and Temperature using Brassica Plants (10-15 min. for 21 days) (see Resource folder) [https://osep.northwestern.edu/sites/default/files/ClimateChange/CO2AndTemperature.pdf](https://osep.northwestern.edu/sites/default/files/ClimateChange/CO2AndTemperature.pdf) 
(Additional Resources) 
Earth Systems Activity: Students model the carbon cycle and it’s atmospheric gases contribute to the greenhouse effect? 
Carbon and Climate: Students run a model of carbon sources and sinks and interpret results to develop their own model of the relationship of the carbon cycle to the Earth’s climate. Students can also work through the content of the entire module called Carbon Connections which includes numerous models and interactives to gain a deeper understanding of the role of carbon in the climate system. |
connection with Earth’s climate. **Images of Change:** Students explore these images of the impacts of climate change over time to develop explanations from evidence of how an impact in one component of the Earth system has effects in other components of the Earth system.

**Storyline:** The activities of humans have significantly altered the biosphere, changing or destroying natural habitats and causing the extinction of many living species. These changes also affect the viability of agriculture or fisheries to support human populations. How can we design ways to reduce the carbon footprint that humans have left behind here on Earth.

**Part D: How do living organisms alter Earth’s processes and structures?**

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Formative Assessment</th>
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</table>
| • The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth’s surface and the life that exists on it. | **Students who understand the concepts are able to:**  
• Construct an argument based on evidence about the simultaneous co-evolution of Earth’s systems and life on Earth. |

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</table>
| Analyze data to create a claim regarding the effect of population | Does population affect the likelihood of heat waves in urban areas? | **Feeling the Heat**  
Students will learn about the | **Feeling the Heat (pdf) (90 mins)** |
| density on temperature levels in urban centers. (HS-ESS2-6),(HS-ESS2-7) | urban heat island effect by investigating which areas of their schoolyard have higher temperatures. Students will analyze data about how the number of heat waves in an urban area has increased over time with population. | Use models to generate evidence regarding the effect of building materials on heat patterns in urban centers. (HS-ESS2-6),(HS-ESS2-7) | Will roof colors impact the temperatures of an urban area? | Raise the Roof Students will use models to explore how roof colors can impact the temperature of an urban area. | Raise the Roof (pdf) (45-60 min) |
| Gather evidence regarding human impacts on CO₂ emissions. (HS-ESS2-6),(HS-ESS2-7) | Can you determine the amount of carbon dioxide your house is adding to the atmosphere? | CO₂ How much do you spew? Students will calculate carbon emissions based on information about a family’s energy consumption. Students will discuss sources of carbon dioxide emissions, and consider ways to decrease carbon dioxide in daily life. | CO₂ How much do you spew? (pdf)(45 mins) |
| Use specific scientific measurement tools to gather evidence regarding human impacts on CO₂ emissions. (HS-ESS2-6),(HS-ESS2-7) | How much carbon dioxide is your appliance adding to the atmosphere? | **Plugged in**  
Students will use a meter to measure the energy use of appliances and electronics, record, and analyze the data, and calculate the CO₂ emitted from an appliance per year. | **Plugged In (pdf) (90mins)** |
|---|---|---|---|
| Determine the feedback factor that affects the population of a species and its effect on coevolution. (HS-ESS2-6),(HS-ESS2-7) | What is coevolution?  
What is an example of feedback? | **Lab 9**: Population Growth: How Do Changes in the Amount and Nature of the Plant Life Available in an Ecosystem Influence Herbivore Population Growth Over Time? | Lab #9 Population Growth Lab pg. 126-138 (approx. 130-200 min.) (see Resources folder)  
**Argument Driven Inquiry in Biology**  
Activity #20 Termite Trail p.239 (approx. 100-150 min.) (see Resource folder)  
**Scientific Argumentation in Biology**  
(Additional Resources) [EarthViewer (IPAd or Android)](...) or for Chrome browsers: Students explore the co-evolution of the geology and biology found on Earth to develop arguments from evidence for the co-evolution of geology and biology found on Earth. If IPads, Androids or... |
Chrome browsers are not available, similar interactives may be found at this link, and this link.

**Climate Reanalyzer**: Students use the Environmental Change Model of the Climate Reanalyzer to study the feedbacks in the climate system.

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<tr>
<th>What It Looks Like in the Classroom</th>
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<tr>
<td>After students have an understanding of the structure and formation of Earth’s surface, they examine how changes to Earth’s surface create feedback. Students also consider what changes to other Earth systems are caused by that feedback. Students analyze data, using tools, technologies, and models to make claims about relationships between changes to Earth’s surface and feedback. Students examine data from the Earth’s weather patterns to model how some weather patterns and Earth events are related to the use of natural resources. Examples of feedback include how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, thus reducing the amount of sunlight reflected from Earth’s surface, which in turn increases surface temperatures and further reduces the amount of ice. Other system interactions include how the loss of ground vegetation causes an increase in water runoff and soil erosion, how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion, or how the loss of wetlands causes a decrease in local humidity that further reduces the wetlands’ extent. Students then provide and explain examples (such as CO₂ emissions, ozone depletion, changing weather patterns, etc.) of the negative and positive feedback that can stabilize and destabilize the environment. Students cite examples of new technologies (such as gasoline cars, hydrogen-fuel-cell cars, biofuel cars, solar power, alternative energy, etc.) and consider their impacts on society and the environment. Students also consider the inorganic carbon cycle and geologic processes. For example, climate feedback could be modeled by understanding relationships between sediments containing carbon (calcium carbonate made by marine organisms) on the seafloor in subduction zones and carbon dioxide released through volcanoes. Students actively explore the properties of water and its effects on Earth materials and surface properties by planning and conducting...</td>
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</table>
investigations. Initially they identify evidence needed to answer a question related to the properties of water and its effects on Earth materials and surface properties. The evidence may be related to the properties, such as heat capacity of water, density of water in its liquid and solid states, and the polar nature of a water molecule due to its molecular structure. The evidence may be related to the effect of the properties of water on energy transfer that causes patterns of temperature, the movement of air, the movement and availability of water at Earth's surface. The evidence may be related to mechanical effects of water on Earth's materials that can be used to infer the effect of water on Earth's surface properties. Some examples include stream transportation and deposition, erosion using variations in soil moisture content, and expansion of water as it freezes. Finally, the evidence may be related to the chemical effects of water on Earth materials that can be used to infer the effect of water on Earth's surface processes. This may include the properties of solubility, the reaction of water on iron, and the properties of water that lower the melting temperature of most solids, and decreases the viscosity of melted rock. Next, students plan out their investigation to align their data collection methods with the evidence they are seeking. For example, they may decide to investigate the mechanical nature of running water on sediment transport and deposition by changing the slope of a stream table. Once their protocol has been designed, they run their investigation and collect data. They analyze and interpret the data, and if necessary, they modify the protocol and run the investigation again.

Students will continue their study of Earth's systems by examining the history of the atmosphere. Students should research the early atmospheric components and the changes that occurred due to plants and other organisms removing carbon dioxide and releasing oxygen. By studying the carbon cycle, students should revisit the idea that matter and energy within a closed system are conserved among the hydrosphere, atmosphere, geosphere, and biosphere. Students should extend their understanding of how human activity affects the concentration of carbon dioxide in the environment and therefore climate. Students' experiences should include synthesizing information from multiple sources and developing quantitative models based on evidence to describe the cycling of carbon among the ocean, atmosphere, soil, and biosphere. Students should understand how biogeochemical cycles provide the foundation for living organisms. Once again, students might use a jigsaw activity to illustrate the relationships between these systems.

Since the Earth formed there has been a co-evolution of Earth's systems and life on Earth. Students explore multiple lines of evidence found in scientific research papers that support this claim, such as the scientific explanations about the composition of the Earth's atmosphere shortly after its formation; current atmospheric composition; evidence for the emergence of photosynthetic organisms; evidence of the effect of the presence of free oxygen on evolution and processes in the other Earth systems; and other evidence that changes in the biosphere affect Earth systems. Students might use a jigsaw activity to explore selected research papers. While reading these papers students identify the methods employed by the scientists, and interpret the data and data visualizations provided in the papers. From this, they evaluate and critique the claims by the scientists. After investigating a variety of research papers, students select
at least two examples to construct oral and written logical arguments about the evolution of photosynthetic organisms led to drastic changes in Earth's atmosphere and oceans in which the free oxygen produced caused worldwide deposition of iron oxide formations, increased weathering due to an oxidizing atmosphere and the evolution of animal life that depends on oxygen for respiration; or identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.

**Interdisciplinary Connections**

*English Language Arts/Literacy*

- Research on feedbacks in the Earth system provides the venue for students to cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- While analyzing scientific research related to feedbacks in the Earth system, students determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

- Conduct short as well as more sustained research projects to answer a question (including a self-generated question) about the effect of water on Earth's systems; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

- Write arguments focused on discipline-specific content related to the simultaneous co-evolution of Earth's systems and life on Earth.
Mathematics

- Reason abstractly and quantitatively while considering feedbacks in the Earth system, such as the feedback created from increased levels of carbon dioxide on global temperature by correlating atmospheric carbon dioxide data and temperature data.

- Use units as a way to understand problems and to guide the solution of multi-step problems related to Earth system feedbacks; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities when exploring Earth system feedbacks or the effects of water on Earth systems materials and processes.

- Represent symbolically the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere, and manipulate the representing symbols. Make sense of quantities and relationships in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

- Use a mathematical model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. Identify important quantities in the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

- Use units as a way to understand the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret units consistently in formulas representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere; choose and interpret the scale and the origin in graphs and data displays representing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

- Define appropriate quantities for the purpose of descriptive modeling of the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities showing the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
Research on Student Learning

Students of all ages may hold the view that the world was always as it is now, or that any changes that have occurred must have been sudden and comprehensive. The students in these studies did not, however, have any formal instruction on the topics investigated. Moreover, middle-school students taught by traditional means are not able to construct coherent explanations about the causes of volcanoes and earthquakes. (NSDL, 2015).

Prior Learning

**Physical science**

- Substances are made from 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.
- 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 others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may 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.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- 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 spontaneously transferred out of hotter regions or objects and into colder ones.
- 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.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

**Life science**

- Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Growth of organisms and population increases are limited by access to resources.
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.
- Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant 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.
- 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 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.
- 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.
- 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.

Natural selection 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.

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.

**Earth and space science**

- Tectonic processes continually generate new ocean sea floor at ridges and destroy old sea floor at trenches.
- 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.
- 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.
- 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.
- 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 only be predicted 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.
- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of 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.
- 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 the level of climate change and 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.

### Connections to Other Courses

**Physical science**

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- The periodic table orders elements horizontally by the number of protons in the atom’s nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.

Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

The availability of energy limits what can occur in any system.

Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.

When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.

Life science

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. 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. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.
- 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 such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.
- 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. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- 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. 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.

Genetic information 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.

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. Evolution is a consequence of the interaction 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 drastic, the opportunity for the species’ evolution is lost.

*Earth and space science*

The sustainbility of human societies and the biodiversity that supports them requires responsible management of natural resources.
Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.

Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

<table>
<thead>
<tr>
<th><strong>Unit Project/ Lab Performance/ Assessments</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MY NASA DATA</strong>: Students select satellite datasets to answer questions related to system interactions and feedbacks.</td>
</tr>
<tr>
<td><strong>Finding the Crater</strong>: Students “visit” different K-T boundary sites, evaluate the evidence found in the cores at each site, find these sites on a map, and predict where the impact crater is located.</td>
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<tr>
<td><strong>Images of Change</strong>: Students explore these images of the impacts of climate change over time to develop explanations from evidence of how an impact in one component of the Earth system has effects in other components of the Earth system.</td>
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<tr>
<td><strong>Climate Reanalyzer</strong>: Students use the Environmental Change Model of the Climate Reanlyzer to study the feedbacks in the climate system.</td>
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<tr>
<td><strong>USGS Realtime Water data</strong> and <strong>Climate data</strong>: Students create and run an investigation to determine the relationship between streamflow and precipitation data, or another parameter.</td>
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<tr>
<td><strong>Greenhouse Effect</strong>: Students explore the atmosphere during the ice age and today. What happens when you add clouds? Change the greenhouse gas concentration and see how the temperature changes. Then compare to the effect of glass panes. Zoom in and see how light interacts with molecules. Do all atmospheric gases contribute to the greenhouse effect?</td>
</tr>
<tr>
<td><strong>Earth Systems Activity</strong>: Students model the carbon cycle and its connection with Earth’s climate.</td>
</tr>
<tr>
<td><strong>Carbon and Climate</strong>: Students run a model of carbon sources and sinks and interpret results to develop their own model of the relationship of the carbon cycle to the Earth’s climate. Students can also work through the content of the entire module called <strong>Carbon Connections</strong> which includes numerous models and inter-actives to gain a deeper understanding of the role of carbon in the...</td>
</tr>
</tbody>
</table>
climate system.

EarthViewer (IPad or Android) or for Chrome browsers: Students explore the co-evolution of the geology and biology found on Earth to develop arguments from evidence for the co-evolution of geology and biology found on Earth. If iPads, Androids or Chrome browsers are not available, similar inter-actives may be found at this [link](#), and this [link](#).

<table>
<thead>
<tr>
<th>Vocabulary</th>
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<tbody>
<tr>
<td>Convection</td>
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<tr>
<td>Thermal Expansion</td>
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<tr>
<td>Climate</td>
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<td>Buoyancy</td>
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<tr>
<td>Biosphere</td>
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<tr>
<td>Hydrosphere</td>
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<tr>
<td>Atmosphere</td>
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<tr>
<td>Geosphere</td>
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<tr>
<td>Biota</td>
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<tr>
<td>Biogeochemical cycles</td>
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<tr>
<td>Hydrologic Cycle</td>
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<tr>
<td>Greenhouse Effect</td>
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<tr>
<td>Absorption spectrum</td>
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<td>Abyssal</td>
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<tr>
<th>Suggested Field Trips</th>
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</thead>
<tbody>
<tr>
<td>Liberty Science Center, NJ State Museum (Trenton), American Museum of Natural History Paterson Great Falls, Garrett Mountain Reservation, Sterling Hills Mine, Liberty State Park Interpretive Center, Rutgers Geology Museum New Jersey School of Conservation, Geology of National Parks, Huber Woods Environmental Center, Geology Virtual Field Trips at Internet 4 Classrooms</td>
</tr>
</tbody>
</table>
# Unit 3: Human Activity and Energy

## Unit Summary

**How is energy generated for human activity?**

In this unit of study, students engage in argument from evidence, develop and use models, ask questions and define problems, construct explanations and design solutions, and evaluate information. This unit focuses on the physics core ideas surrounding energy and energy transformations as related to the Earth System core idea of energy needs for human activity. Students create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. They apply engineering design principles to design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. Within this unit students also apply the core ideas of related to the behavior of electromagnetic energy to evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. They develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction (secondary concept). They apply these core ideas to communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. At the basis of our energy needs is the need for resources to create energy, and therefore students evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios. The crosscutting concepts of systems and system models, energy and matter, cause and effect, and stability and change are called out as an organizing concept for these disciplinary core ideas.

This unit is based on HS-ESS3-2, HS-PS3-1, HS-PS3-2, HS-PS3-3, HS-PS3-5 (secondary to HS-PS3-3), HS-PS4-3, and HS-PS4-5.

*Note: The disciplinary core ideas, science and engineering practices, and crosscutting concepts can be taught in either this course or in a high school physics course.*

## Student Learning Objectives

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios. *Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where*
### Possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen. (HS-ESS3-2)

### Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. (Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.) (Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.) (HS-PS3-1)

### Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). (Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.) (HS-PS3-2)

### Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* (Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.) (HS-PS3-3)

### Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. (Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.) (Assessment Boundary: Assessment is limited to systems containing two objects.) (HS-PS3-5)

### Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. (Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a
phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [Assessment Boundary: Assessment does not include using quantum theory.] (HS-PS4-3)

Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.* [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.] (HS-PS4-5)

Storyline - As a scientist can we mimic nature (solar energy that is used by plants to convert inorganic compound into organic) to create energy resources that are cost effective and sustainable.

Part A Overreaching Question: What is the best energy source for a home? How would I meet the energy needs of a house of the future?

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Formative Assessment</th>
</tr>
</thead>
</table>
| • All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.  
• Models can be used to simulate systems and interactions, including energy, matter, and information flows, within and between systems at different scales.  
• Engineers continuously modify design solutions to increase benefits while decreasing costs and risks.  
• Analysis of costs and benefits is a critical aspect of decisions about technology.  
• Scientific knowledge indicates what can happen in natural systems, not what should happen. The latter involves | Students who understand the concepts are able to:  
• Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations).  
• Use models to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost–benefit ratios, scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, and ethical considerations). |
ethics, values, and human decisions about the use of knowledge.

- New technologies can have deep impacts on society and the environment, including some that were not anticipated.
- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Many decisions are made not using science alone, but instead relying on social and cultural contexts to resolve issues.

<table>
<thead>
<tr>
<th>Standards and Objectives</th>
<th>Essential Question</th>
<th>Activities</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify the environmental and social issues that the new generation of the scientific community will face. (HS-ESS3-2)</td>
<td>What role do scientists play in solving environmental issues?</td>
<td>Lab- Hydraulic fracturing&lt;br&gt;Students will research and identify the pros and cons of hydraulic fracturing of the natural gas vs the traditional extraction.&lt;br&gt;Students will write a research paper on Hydraulic Fracturing</td>
<td>Lab: Hydraulic fracturing of natural gas from shale deposits vs traditional extraction; Timeline (200 minutes)&lt;br&gt;Video on Hydraulic fracturing <a href="http://www.youtube.com/watch?v=IB3FOjpy7s">http://www.youtube.com/watch?v=IB3FOjpy7s</a></td>
</tr>
<tr>
<td>Explore how scientists work to synthesize and create technology that will solve environmental, health, and economic issues for the future</td>
<td>What role do scientists play in creating self efficient and cost effective products?</td>
<td>Lab-Carbon Stabilizing Wedge&lt;br&gt;Students will identify the technologies currently available that can substantially cut carbon</td>
<td>Lab: Carbon Stabilization Wedge; Timeline (120 minutes)</td>
</tr>
</tbody>
</table>
| generations. (HS-ESS3-2) | emissions, and verbally communicate the rationale for their selections. | Identify the role of scientists in solving world problems. (HS-ESS3-2) | What social, moral, and ethical values do scientist have to keep in mind when solving such problems? | Lab- One for All: A Natural Resource
Students will understand their civil role to solve future world problems. Students will understand the role of government to solve environmental, social, and health problems.
**Lab- Natural Climate Assessments**
Students will calculate and use data to predict how long it will take to run out of non renewable resources. Students will create a graph representations to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity. | Lab: [One For All: A Natural Resources Game](#); Timeline (90 minutes)
Lab: [National Climate Assessment](#); Timeline (120 minutes) |

**Storyline** - As a scientist what role does the use of mathematics play in creating technology that is cost effective and efficient.
**Part B overreaching Question:** How can we use mathematics in decision-making about energy resources?

<table>
<thead>
<tr>
<th>Concepts</th>
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</tr>
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<tbody>
<tr>
<td>• That there is a single quantity called energy is due to the fact that a system’s total energy is conserved even as, within the system, energy is continually transferred from one object to another and between its various possible forms.</td>
<td></td>
</tr>
<tr>
<td>• Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.</td>
<td></td>
</tr>
<tr>
<td>• Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.</td>
<td></td>
</tr>
<tr>
<td>• The availability of energy limits what can occur in any system.</td>
<td></td>
</tr>
<tr>
<td>• Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximation inherent in models.</td>
<td></td>
</tr>
<tr>
<td>• Science assumes that the universe is a vast single system in which basic laws are consistent.</td>
<td></td>
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</tbody>
</table>

**Students who understand the concepts are able to:**

- Use basic algebraic expressions or computations to create a computational model to calculate the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and energy flows in and out of the system are known.
- Explain the meaning of mathematical expressions used to model the change in the energy of one component in a system (limited to two or three components) when the change in energy of the other component(s) and out of the system are known.

<table>
<thead>
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<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpret the first Law of Thermodynamics – The Total Energy of the universe is constant. Analyze statistical data to interpret the Entropy of microstate and macrostate and how do they relate. (HS-PS3-1)</td>
<td>How do we measure the energy flow from one system to another? How do we measure the heat absorbed or released during a chemical reaction?</td>
<td><strong>Lab-Energy Skate Park</strong>  Students will explore conservation of energy with a stimulated skater.</td>
<td>Lab Stimulation: Energy Skate Park: Basics:</td>
</tr>
</tbody>
</table>
Calculate the total energy of a system and show how the energy moves in or out of a system by heat or work. (HS-PS3-1)

What does it mean that the total energy of the universe is constant?

**Lab-Know Your Energy Costs**
Students will calculate energy that is being consumed in school, house, or neighborhood.

**Lab: Know Your Energy Costs:**

### Storyline - As a scientist why it is important to understand energy and how it works. What are some of the direct impacts that energy has on us as humans.

**Part C Overreaching Question:** *I have heard about it since kindergarten but what is energy?*

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Formative Assessment</th>
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<tbody>
<tr>
<td>• Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system.</td>
<td>Students who understand the concepts are able to:</td>
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<tr>
<td>• At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.</td>
<td>• Develop and use models based on evidence to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).</td>
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<tr>
<td>• These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles).</td>
<td>• Develop and use models based on evidence to illustrate that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.</td>
</tr>
<tr>
<td>• In some cases, the relative position energy can be thought of as stored in fields (which mediate interactions between particles).</td>
<td>• Use mathematical expressions to quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compressions of a spring) and how kinetic energy depends on mass and speed.</td>
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<tr>
<td>• Radiation is a phenomenon in which energy stored in fields</td>
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- Energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems.

- Use mathematical expressions and the concept of conservation of energy to predict and describe system behavior.

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</table>
| Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. (HS-PS3-2) | What is energy?  
How is energy transferred between two objects? | Lab-Earth: Planet of Alternated State  
Students will use earth’s Data to show how energy of the planet is constantly changing | Lab: Earth: Planet of Altered States: |
| Analyze how Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which | What role does the state of matter play in the energy transfer?  
What are the types of motions in the microscopic state?  
What is meant with the statement that “energy is not created nor destroyed”? | Lab- Climate Reanalyze  
Students will use NASA’s data to show changes in temperature on land and on the oceans. Students will use graphs to represent the change of energy on the planet over time  
Lab-Work and Energy  
Students will calculate the Work done by the surroundings to the system | Lab: Climate Reanalyzer: |
the energy is transferred is called work. (work or heat) (HS-PS3-2)

Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. (HS-PS3-2)

What happened to the particles as energy is absorbed or released? What are the main types of energy?

Students will calculate the energy flow from the system to the surroundings.

Lab: Work and Energy Workbook
Students will calculate work done by the system to the surroundings.

Lab: Work and Energy Workbook Labs

Storyline - Story line – What role do you play as a scientist to solve environmental problems and impact humans’ life in a positive way.

Part D Overreaching Question: Superstorm Sandy devastated the New Jersey Shore and demonstrated to the public how vulnerable our infrastructure is. Using your understandings of energy, design a low technology system that would insure the availability of energy to residents if catastrophic damage to the grid occurs again.

Concepts

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- Modern civilization depends on major technological systems.

Formative Assessment

Students who understand the concepts are able to:

- Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
- Analyze a device to convert one form of energy into another form of energy by specifying criteria and constraints for successful solutions.
Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

- News technologies can have deep impacts on society and the environment, including some that were not anticipated.
- Analysis of costs and benefits is a critical aspect of decisions about technology.
- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
- Humanity faces major global challenges today, such as the need for supplies of clean water or for energy sources that minimize pollution that can be addressed through engineering. These global challenges also may have manifestations in local communities.

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| Design and create objects that solve environmental problems. Create efficient and affordable house models. Apply the law of conservation energy to build and find solutions. Find solutions | • How do we use the work/energy theorem to create and design instruments that have positive impact on humans?  
• How can we use the laws of the conservation of the energy to solve environmental, social and health issues? | **Lab- Build a Solar House**  
Students will construct a model house and measure the energy efficiency of the solar heat. | Lab: Build a Solar House; in the unit Folder |

- Use mathematical models and/or computer simulations to predict the effects of a device that converts one form of energy into another form of energy.
to environmental and social issues that have a positive impact on society. HS-PS3-2, HS-ETS-1-4

- How do we apply energy conservation to solve environmental issues?

| Storyline: As a scientist how can we use the dual nature of light to explain and better understand the physical world around us. |
| Part E Overreaching Question: How can electromagnetic radiation be both a wave and a particle at the same time? |

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<tr>
<td>- 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.</td>
<td>Students who understand the concepts are able to:</td>
</tr>
<tr>
<td>- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.</td>
<td>- Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other.</td>
</tr>
<tr>
<td>- A wave model or a particle model (e.g., physical, mathematical, computer models) can be used to describe electromagnetic radiation—including energy, matter, and information flows—within and between systems at different scales.</td>
<td>- Evaluate experimental evidence that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other.</td>
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<tr>
<td>- A wave model and a particle model of electromagnetic radiation are based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is</td>
<td>- Use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions—including energy, matter, and information flows—within and between systems at different scales.</td>
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generally modified in light of this new evidence.

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<tr>
<td>Compare and contrast the properties and behavior of waves vs matter. (HS-PS4-3)</td>
<td>What is the Electromagnetic spectrum? What are waves?</td>
<td><strong>Lab-Introduction to Electromagnetic Spectrum</strong>&lt;br&gt;Students will identify waves by their frequency and wavelength in the Electromagnetic spectrum</td>
<td>Lab: <a href="#">Introduction to the Electromagnetic Spectrum</a> NASA background resource</td>
</tr>
<tr>
<td>Analyze the dual nature of light as wave and as a matter. (HS-PS4-3)</td>
<td>What is meant by the phrase dual nature?</td>
<td><strong>Lab- Technology for Imaging the Universe</strong>&lt;br&gt;Students will discover how scientist discover new mysteries by using innovative technology</td>
<td>Lab: <a href="#">Technology for Imaging the Universe</a> NASA background resource</td>
</tr>
<tr>
<td>Identify properties of waves. (HS-PS4-3)</td>
<td>What are the properties of waves?</td>
<td><strong>Lab-Making Waves</strong>&lt;br&gt;Students will organize different energy images into a logical pattern. Students will investigate and research different sections of the electromagnetic spectrum and share their findings with the class.</td>
<td>Lab: <a href="#">NASA LAUNCHPAD: Making Waves</a> NASA e-Clips activity on the electromagnetic spectrum</td>
</tr>
<tr>
<td>Use the dual nature of light to explain that matter also has a dual nature. (HS-PS4-3) (HS-PS4-5)</td>
<td>How has our understanding of the structure of matter changed?</td>
<td><strong>Lab: Radio Waves and Electromagnetic Fields</strong>&lt;br&gt;Students will identify properties of waves such as propagation, and interference. <strong>Lab- Wave/Particle Dualism</strong></td>
<td>Lab: <a href="#">Radio Waves and Electromagnetic Fields</a>; Timeline (120 minutes)</td>
</tr>
</tbody>
</table>
Students will prove the dual nature of light as wave and as particle.

Storyline: As future scientists, what role does technology play in solving global issues?

Part F Overreaching Question: How does the International Space Station power all of its equipment? How do astronauts communicate with people on the ground?

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<tr>
<td>Solar cells are human-made devices that capture the sun’s energy and produce electrical energy.</td>
<td>Students who understand the concepts are able to:</td>
</tr>
<tr>
<td>Photoelectric materials emit electrons when they absorb light of a high enough frequency.</td>
<td>- Communicate qualitative technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.</td>
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<tr>
<td>Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.</td>
<td>- Communicate technical information or ideas about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy in multiple formats (including orally, graphically, textually, and mathematically).</td>
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<tr>
<td>Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.</td>
<td>- Analyze technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy by specifying criteria and constraints for successful solutions.</td>
</tr>
<tr>
<td>Humanity faces major global challenges today, such as the need for supplies of clean water and food and for energy</td>
<td>- Evaluate a solution offered by technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy based on scientific knowledge, student-generated sources of evidence, prioritized</td>
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</table>
sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- Wave interaction with matter systems can be designed to transmit and capture information and energy.
- Science and engineering complement each other in the cycle known as research and development (R&D).
- Modern civilization depends on major technological systems.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

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<tr>
<td>Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. (HS-ESS3-2)</td>
<td>How do waves interact with matter?</td>
<td><strong>Lab-Refraction</strong> Students will determine what happened if waves interfere constructively or distractively</td>
<td>Lab: <a href="https://phet.colorado.edu/en/simulation/wave-interferencePHeT">Refraction</a>; Timeline(60 minutes)</td>
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<td><strong>Lab-Wave Interference</strong> Students will determine what happen to the waves interference when waves of</td>
<td>Lab: <a href="https://phet.colorado.edu/en/simulation/wave-interferencePHeT">Thin Film Refraction</a>;</td>
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</table>

| Criteria, and tradeoff considerations. |
| Synthesize cost effective technology instruments to improve and facilitate human life. (HS-ESS3-2) | How is the interaction of the waves with matter is used to invent new technology? | **Lab-Thin Film Refraction**  
Students will predict the behavior of water, sound, or light when you have two sources (predict what will happen in both constructive and in destructive areas)  
**Lab- Photoelectric Effect**  
Students will explore the photoelectric effect and prove how the light behaves as a particle when interacting with metals. | Timeline (60 minutes)  
Lab: **Wave Interference**: Timeline (60 minutes)  
Lab: **Thin Film Interference**: Timeline (90 minutes)  
Lab: **Photoelectric Effect Phet**: Timeline (60 minutes) Phet simulation addressing evidence for particle nature of electromagnetic radiation  
Lab: **Photoelectric Effect OSP**: Timeline (60 minutes) |
| Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. (HS-ESS3-2) | What are the practical uses of the waves in medical, engineering, media, and technology uses? | **Lab-Interaction of Molecules with Electromagnetic Radiation**  
Students will identify the effects that microwaves, infrared, visible light, and ultraviolet radiations have when they interact with various molecules.  
**Lab- X-ray Technology**  
Students will discover how X-Rays work and what is their practical use in the medical field. | Lab: **Interaction of Molecules with Electromagnetic Radiation**: Timeline (120 minutes)  
Lab: **X-ray Technology**: OSP Simulation; Timeline (120 minutes) |
Unit Project/Lab Performance Assessment

Build a roller coaster and calculate work, power, kinetic energy, potential energy and speed at various points of the coaster.  
  
Lab1  
Lab2

What it Looks Like in the Classroom

In this unit, students explore the disciplinary core ideas around energy resources while applying core ideas from physical science related to energy. Working from the premise that all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs, risks, and benefits, students use cost–benefit ratios to evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources. For example, students might investigate the real-world technique of using hydraulic fracturing to extract natural gas from shale deposits versus other traditional means of acquiring energy from natural resources. Students will synthesize information from a range of sources into a coherent understanding of competing design solutions for extracting and utilizing energy and mineral resources. As students evaluate competing design solutions, they should consider that new technologies could have deep impacts on society and the environment, including some that were not anticipated. Some of these impacts could raise ethical issues for which science does not provide answers or solutions. In their evaluations, students should make sense of quantities and relationships associated with developing, managing, and utilizing energy and mineral resources. Mathematical models can be used to explain their evaluations. Students might represent their understanding by conducting a Socratic seminar as a way to present opposing views. Students should consider and discuss decisions about designs in scientific, social, and cultural contexts.

Related to the integration of physical science core ideas, the following classroom methods may be applied; however the big idea centered on our energy resources is in the forefront throughout the unit.

Students will develop an understanding that energy is a quantitative property. They will explore energy in systems as a function of the motion and interactions of matter and radiation within systems. Energy can be detected and measured at the macroscopic scale as the phenomena of motion, sound, light, and thermal energy. Students will also learn that these forms of energy can be modeled in terms of the energy associated with the motion of particles or the energy stored in fields (gravitational, electric, magnetic,) that mediate interactions between particles.
Students are ultimately able to develop models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles, or objects, and energy associated with the relative position of particles, or objects. In some cases, the relative position energy can be thought of as stored in fields. Students should be able to qualitatively show that an object in a gravitational field has a greater amount of potential energy as it is put into higher and higher locations in that field. An example of this could be investigating how an object, such as a ball, when released from successively higher and higher positions hits the ground at greater and greater velocities (kinetic energy).

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<th>Kinetic Energy</th>
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<tr>
<td>Potential Energy</td>
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<td>Work</td>
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In these kinds of investigations, students should understand how to obtain the original potential energy of the object. They should know that when work is done on an object, the energy of the object changes, such as when the wrecking ball of a demolition machine is raised. Work can be calculated ($W=Fd$), appreciated, and understood as a concept. Students should recognize the relationship between the work done on an object and the potential energy of objects. Considering an object that collides with the ground, students should be able to list a variety of ways the kinetic energy is transferred upon impact. For example, kinetic energy is transferred to thermal energy or to sound. Emphasis on the law of conservation of energy should be evident at all points of this discussion. Energy cannot be created or destroyed. It only moves between one place and another, between objects and/or fields, or between systems. Students should demonstrate their understanding of energy conservation and transfer using models. Models should be evidence based and illustrate the relationship between energy at the bulk scale and motion and position at the particle scale. Models should also illustrate conservation of energy. Examples of models might include diagrams, drawings, written descriptions, or computer simulations. Modeling should include strategic use of digital media in presentations to enhance understanding.

Students should understand that changes of energy in a system are described in terms of energy flows into, out of, and within the system. They should also be able to describe the components of a system. Basic algebraic expressions or computations should be
used to model the energy of one component of a system (limited to two or three components) when the change in energy of the other components is known. At this point, the law of conservation of energy should be evident numerically through analysis of calculated data.

Students also should use mathematical expressions to quantify how stored energy in a system depends on configuration—for example, the stretching or compression of a spring. Students might calculate the potential energy of springs. Students should also consider how stored energy depends on configuration in terms of relative positions of charged particles. Students might perform investigations with capacitors. They should also know that the availability of energy limits what can occur in any system.

Another way for students to illustrate that, in systems, energy can be transformed into various types of energy (both potential and kinetic) is to describe and diagram the changes in energy that occur in systems. For example, students could diagram steps showing the transformations of energy that occur when a student uses a yo-yo or the transformations of energy that occur in a burning candle. Ultimately, students might also diagram the steps showing transformations of energy, from fusion in the sun to the food that we eat. Students should include the phenomenon of radiation, in which energy stored in fields can move across spaces, when appropriate.

In this unit, students will also design, build, and refine a device that works within given constraints to convert one form of energy into another based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. They should also use mathematical models or computer simulations to predict the effects of a device that converts one form of energy into another.

To fulfill the engineering component of this unit as described above, students might be assigned an energy project to explore energy transformation and conservation. This could be a computer simulation, practical model, or model with Excel-calculated formulae to verify expected results. Students could also design and build a Rube Goldberg apparatus to perform a given task. After conducting research, students could make claims or defend arguments about various green energy sources. Properties of dams, solar cells, solar ovens, generators, and turbines could be explored through simulations. Evaluations of devices should be both qualitative and quantitative, and analysis of costs and benefits is a critical aspect of design decisions.

When focusing on engineering, students keep in mind that modern civilization depends on major technological systems, and that engineers continuously modify these systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Students should also develop an understanding that new technologies can have deep impacts on society and the environment, including some that were not anticipated.
The suggested methods that follow focus on the PE's related to waves and electromagnetic energy.

Students are then introduced to the idea that electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Students should have an understanding of the wave model from their work in the previous unit. Because all observations cannot be explained with one model, students should explore the wave and particle models and make determinations about which is most appropriate in which situations. Students might begin the unit by exploring the history of the wave and particle models. In their research, students should evaluate the hypotheses, data, analysis, and conclusions in text and cite evidence to support their analysis. Students should also be able to support claims, evidence, and reasoning with mathematical expressions representing wave and particle models of electromagnetic radiation, rearranging formulas to highlight a quantity of interest, and making sense of quantities and relationships.

Students must be able to determine which model is most appropriate under which circumstances by evaluating experimental evidence, claims, evidence, and reasoning. Students may research this question and present their findings in an argumentative essay. Students might consider particular phenomena, such as diffraction, and determine whether the wave or particle model provides the best explanation. Using a Venn diagram, students could differentiate between phenomena and models. Students use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions.

Some wave applications include:
- Diffraction—Students can be shown how waves bend around obstacles in a wave tank or explore using a prism and a laser.
- Polarization—Students could explore this phenomenon through its use in 3D movies, computer monitors, cell phones, and sunglasses.
- Doppler shift—Students can consider applications of Doppler shift in astronomy and weather.
- Wave interference—A wave tank or computer simulation could be used to illustrate interference.
- Transmission—Wave transmission can be modeled using computer simulations.

Some particle applications include:
- Refraction—Students can explore light bending as changes in media using prisms or water. They can also use Snell’s Law to describe the relationship between angles of incidence and refraction.
• Reflection—Students should develop an understanding of incident rays and reflected rays using the law of reflection. They might explore this concept using a wave tank.
• Ray diagrams—Students can create lens ray diagrams on paper.
• Photoelectric effect—Students can explore solar cells to understand this phenomenon. Note that if this course is sequenced before chemistry, students will not have an understanding of electrons.
• Piezoelectric effect—Students might research this phenomenon using solar cells and ultrasound analogies.

Students understand that the energy in a wave depends on its frequency as well as its amplitude (energy is proportional to amplitude squared). Different frequencies of electromagnetic radiation also have different abilities to penetrate matter. When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. For example ultraviolet light penetrates the skin and can cause skin cancer, while X-rays and gamma rays can permeate deep tissue and cause radiation poisoning. Students should explore these cause-and-effect relationships through an investigation of scientific text. They should cite evidence from multiple sources; evaluate hypotheses, data, analysis, and conclusions; and assess strengths and limitations.

To explore color and energy, students could explore Herschel’s experiment in which thermometers were placed in different colors to see which color was “hottest.” It turned out that Herschel’s control, placed in what is now known as infrared, was the hottest of all. This demonstrated that there are wavelengths of electromagnetic radiation beyond the visible spectrum.

Students research how different spectra of light interact with matter, such as the effects of electromagnetic radiation on the human body—effects of nuclear disasters on plant workers (Chernobyl, Fukushima, Three Mile Island), skin cancer, medical X-rays, diagnostic imaging technology, etc. Specifically, they should evaluate the validity and reliability of source material and determine cause-and-effect relationships. The final product could be a written essay, presentation, model, or oral debate. Research topics might include:

The engineering component of this unit includes exploring how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. Students might investigate solar cells and how they work, including a qualitative description of the photoelectric effect. Photoelectric materials emit electrons when they absorb light of a high enough frequency. This is another opportunity to discuss solar cells. Other technologies that use the photoelectric effect include
automatic doors, safety lights, television camera tubes, light-activated counters, intrusion alarms, and streetlights.

Students evaluate the efficiency and cost-effectiveness of modern solar cell technology. Given existing solar cells, students may consider how they rate in terms of one-time purchase, aesthetics, maintenance, and overall total cost of ownership. They evaluate this energy solution scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

The advantages and disadvantages of various electromagnetic frequencies in modern technology are explored using examples such as astronomical telescopes (microwave, infrared, visible, etc.), LiDAR, solar panel cells, CDs, Blu-ray, infrared remote controls or car fobs, infrared motion detection cameras, computer memory storage, or fiber optics. Students create models of the interactions in these common types of systems and explain their model using either written or oral media.

Integration of engineering-

Students communicate technical information comparing energy resources while integrating their knowledge of physical science and energy transformations. ETS1-1 and ETS1-3 are identified as appropriate connections so that students can analyze a major global challenge and evaluate a solution to a complex real-world problem.

Integration of PE's and DCI's from other units-

This unit ties in with the physical science model curriculum units on energy (Unit 4) and on waves (Unit 7) as they pertain to energy resources. Refer to those units for additional classroom integration methods. Additionally, consider linking the performance expectation related to nuclear energy with this unit (HS-PS1-8).

Interdisciplinary Connections

English Language Art/Literacy

- Collect relevant data across a broad spectrum of sources about the distribution of energy in a system and assess the strengths and limitations of each source.
- Synthesize findings from experimental data into a coherent understanding of energy distribution in a system.
- Cite specific textual evidence to evaluate competing design solutions for developing, managing, and utilizing energy resources.
based on cost–benefit ratios.

- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.

- Integrate and evaluate multiple design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios in order to reveal meaningful patterns and trends.

- Evaluate the hypotheses, data, analysis, and conclusions of competing design solutions for developing, managing, and utilizing energy resources based on cost–benefit ratios, verifying the data when possible and corroborating or challenging conclusions with other design solutions.

- Synthesize data from multiple sources of information in order to create data sets that inform design decisions and create a coherent understanding of developing, managing, and utilizing energy resources.

- Make strategic use of digital media in presentations to enhance understanding of the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.

- Make strategic use of digital media in presentations to support the claim that energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects).

- Conduct short as well as more sustained research projects to describe energy conversions as energy flows into, out of, and within systems.

- Integrate and evaluate multiple sources of information presented in diverse formats and media to describe energy conversions as energy flows into, out of, and within systems.

- Evaluate scientific text regarding energy conversions to determine the validity of the claim that although energy cannot be destroyed, it can be converted into less useful forms.

- Assess the extent to which the reasoning and evidence in a text supports the author’s claim that electromagnetic radiation can
be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

- Cite specific textual evidence to support the wave model or particle model in describing electromagnetic radiation, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text relating that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

- Assess the extent to which the reasoning and evidence in a text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter support the author’s claim or recommendation.

- Cite textual evidence to support analysis of science and technical texts describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., qualitative data, video multimedia) in order to address the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

- Gather relevant information from multiple authoritative print and digital sources describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

- Write informative/explanatory texts about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, including the narration of scientific procedures, experiments, or technical processes.

- Integrate and evaluate multiple sources of information about technological devices that use the principles of wave behavior and
wave interactions with matter to transmit and capture information and energy, presented in diverse formats and media (e.g., quantitative data, video, multimedia), in order to address a question or solve a problem.

**Mathematics**

- Use a mathematical model to describe energy distribution in a system when two components of different temperature are combined. Identify important quantities in energy distribution in a system when two components of different temperature are combined and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities of the properties of water and their effects on Earth materials and surface processes.
- Use symbols to represent an explanation of the best of multiple design solutions for developing, managing, and utilizing energy and mineral resources and manipulate the representing symbols. Make sense of quantities and relationships in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources symbolically and manipulate the representing symbols.
- Use a mathematical model to explain the evaluation of multiple design solutions for developing, managing, and utilizing energy and mineral resources. Identify important quantities in cost–benefit ratios for multiple design solutions for developing, managing, and utilizing energy and mineral resources and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Represent symbolically an explanation about the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known, and manipulate the representing symbols. Make sense of quantities and relationships about the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known symbolically, and manipulate the representing symbols.
- Use a mathematical model to explain the notion that energy is a quantitative property of a system and that the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known. Identify important quantities in energy of components in systems and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
• Use units as a way to understand how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret units consistently in formulas representing how the change in the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known; choose and interpret the scale and the origin in graphs and data displays representing that the energy of one component in a system can be calculated when the change in energy of the other component(s) and energy flows in and out of the system are known.

• Represent the conversion of one form of energy into another symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the conversion of one form of energy into another.

• Use a mathematical model of how energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects). Identify important quantities representing how the energy at the macroscopic scale can be accounted for as a combination of energy associated with motions of particles (objects) and energy associated with the relative position of particles (objects), and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

• Use a mathematical model to describe the conversion of one form of energy into another and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the conversion of one form of energy into another and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

• Use units as a way to understand the conversion of one form of energy into another; choose and interpret units consistently in formulas representing energy conversions as energy flows into, out of, and within systems; choose and interpret the scale and the origin in graphs and data displays representing energy conversions as energy flows into, out of, and within systems.

• Define appropriate quantities for the purpose of descriptive modeling of a device to convert one form of energy into another form of energy.

• Represent symbolically that electromagnetic radiation can be described either by a wave model or a particle model and that for some situations one model is more useful than the other, and manipulate the representing symbols.

• Make sense of quantities and relationships between the wave model and the particle model of electromagnetic radiation.
- Interpret expressions that represent the wave model and particle model of electromagnetic radiation in terms of the usefulness of the model depending on the situation.
- Choose and produce an equivalent form of an expression to reveal and explain properties of electromagnetic radiation.
- Rearrange formulas representing electromagnetic radiation to highlight a quantity of interest, using the same reasoning as in solving equations.
- Represent the principles of wave behavior and wave interactions with matter to transmit and capture energy symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the principles of wave behavior and wave interactions with matter to transmit and capture energy.
- Use a mathematical model to describe the principles of wave behavior and wave interactions with matter to transmit and capture information and energy and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

### Modification for Differentiation at all Levels

*(Note: Teachers identify the modifications that they will use in the unit. See NGSS Appendix D: All Standards, All Students/Case Studies for vignettes and explanations of the modifications.)*

- Structure lessons around questions that are authentic, relate to students’ interests, social/family background and knowledge of their community.
- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds.
and cultures (e.g. multiple representation and multimodal experiences).

- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.
- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#VXmoXcfD_UA).

**Research on Student Learning**

Students rarely think energy is measurable and quantifiable. Students' alternative conceptualizations of energy influence their interpretations of textbook representations of energy.

Students tend to think that energy transformations involve only one form of energy at a time. Although they develop some skill in identifying different forms of energy, in most cases their descriptions of energy-change focus only on forms which have perceivable effects. The transformation of motion to heat seems to be difficult for students to accept, especially in cases with no temperature increase. Finally, it may not be clear to students that some forms of energy, such as light, sound, and chemical energy, can be used to make things happen.

The idea of energy conservation seems counterintuitive to students who hold on to the everyday use of the term energy, but teaching heat dissipation ideas at the same time as energy conservation ideas may help alleviate this difficulty. Even after instruction, however, students do not seem to appreciate that energy conservation is a useful way to explain phenomena. A key difficulty students have in understanding conservation appears to derive from not considering the appropriate system and environment. In addition, high-school students tend to use their conceptualizations of energy to interpret energy conservation ideas. For example, some students interpret the idea that "energy is not created or destroyed" to mean that energy is stored up in the system and can even be released again in its original form. Or, students may believe that no energy remains at the end of a
process, but may say that "energy is not lost" because an effect was caused during the process (for example, a weight was lifted). Although teaching approaches which accommodate students' difficulties about energy appear to be more successful than traditional science instruction, the main deficiencies outlined above remain despite these approaches (NSDL, 2015)

<table>
<thead>
<tr>
<th>Physical science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substances are made from 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.</td>
</tr>
<tr>
<td>Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.</td>
</tr>
<tr>
<td>Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.</td>
</tr>
<tr>
<td>In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.</td>
</tr>
<tr>
<td>Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).</td>
</tr>
<tr>
<td>The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>A system of objects may also contain stored (potential) energy, depending on their relative positions.</td>
</tr>
</tbody>
</table>
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.

When the motion energy of an object changes, there is inevitably some other change in energy at the same time.

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 spontaneously transferred out of hotter regions or objects and into colder ones.

When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

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.

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.

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.

A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.

However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

Life Science

Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.

In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.
- Growth of organisms and population increases are limited by access to resources.

- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.

- 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.

**Earth and space science**

- 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.

- 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 geologic processes.

- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of 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.
Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.

Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into
or out of the system.

- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

- The availability of energy limits what can occur in any system.

- Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis.

Life science

- 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 such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.

- 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. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are
combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.

- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

- 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. Thus sustaining biodiversity so that ecosystem functioning 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.

**Earth and space science**

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.

- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.

- Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth’s surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth’s interior and gravitational movement of denser materials toward the interior.

- The foundation for Earth’s global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy’s re-radiation into space.

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.

- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
Resource availability has guided the development of human society.

All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

<table>
<thead>
<tr>
<th>Samples of Open Education Resources for this Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon Stabilization Wedge</strong>: Students play this game in order to evaluate competing design solutions for developing, managing, and utilizing energy resources based on cost-benefit ratios.</td>
</tr>
<tr>
<td><strong>One For All: A Natural Resources Game</strong>: Identify a strategy that would produce a sustainable use of resources in a simulation game. Draw parallels between the chips used in the game and renewable resources upon which people depend. Draw parallels between the actions of participants in the game and the actions of people or governments in real-world situations.</td>
</tr>
<tr>
<td><strong>National Climate Assessment</strong>: Students explore the simulations found at this website in order to create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.</td>
</tr>
<tr>
<td><strong>Know Your Energy Costs</strong>: The goal of this activity is to become aware of how much energy you use at school — and the financial and environmental costs.</td>
</tr>
<tr>
<td><strong>Earth: Planet of Altered States</strong>: Watch a segment of a NASA video and discuss how the earth is constantly changing.</td>
</tr>
<tr>
<td><strong>Climate Reanalyzer</strong>: Students use the Environmental Change Model of the Climate Reanlyzer to study the feedbacks in the climate system.</td>
</tr>
<tr>
<td><strong>Energy Skate Park: Basics</strong>: Learn about conservation of energy with a skater gal! Explore different tracks and view the kinetic energy, potential energy and friction as she moves. Build your own tracks, ramps, and jumps for the skater.</td>
</tr>
<tr>
<td><strong>Work and Energy Workbook Labs</strong>: The lab description pages describe the question and purpose of each lab and provide a short description of what should be included in the student lab report.</td>
</tr>
</tbody>
</table>
| **Build a Solar House**: Construct and measure the energy efficiency and solar heat gain of a cardboard model house. Use a light bulb heater to imitate a real furnace and a temperature sensor to monitor and regulate the internal temperature of the house. Use a bright bulb in a gooseneck lamp to model sunlight at different times of the year, and test the effectiveness of windows for passive
solar heating.

**Introduction to the Electromagnetic Spectrum**: NASA background resource

**Technology for Imaging the Universe**: NASA background resource

**NASA LAUNCHPAD: Making Waves**: NASA e-Clips activity on the electromagnetic spectrum

**Radio Waves and Electromagnetic Fields**: Phet simulation demonstrating wave generation, propagation and detection with antennas.


**Wave Interference**: Phet simulation of both mechanical and optical wave phenomena

**Thin Film Interference**: OSP simulation of thin film interference for various wavelengths of visible light

**Photoelectric Effect Phet**: Phet simulation addressing evidence for particle nature of electromagnetic radiation

**Photoelectric Effect** OSP: Open Source Physics simulation of the photoelectric effect.

**Interaction of Molecules with Electromagnetic Radiation**: Phet simulation exploring the effect of microwave, infrared, visible and ultraviolet radiation on various molecules.

**Wave/Particle Dualism**: Phet simulation of wave and particle views of interference phenomena.

**X-ray Technology**: OSP Simulation of optimization of X-ray contrast by varying energy of X-rays, materials characteristics and measurement parameters

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**Appendix A: NGSS and Foundations for the Unit**

Use a model to describe how variations in the flow of energy into and out of Earth’s systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-
100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.] (HS-ESS2-4)

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.] (HS-ESS2-6)

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. [Clarification Statement: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-1)

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. [Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-2)

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. [Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-3)

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. [Note: See Three-Dimensional Teaching and Learning Section for examples.] (HS-ETS1-4)

The Student Learning Objectives above were developed using the following elements from the NRC document A Framework for K-12 Science Education:

- **Science and Engineering Practices**
- **Disciplinary Core Ideas**
- **Crosscutting Concepts**
### Developing and Using Models

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1),(HS-ESS2-3),(HS-ESS2-6)
- Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4)

### Asking Questions and Defining Problems

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)

### Using Mathematics and Computational Thinking

- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)

### Constructing Explanations and Designing Solutions

- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)

### ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth’s orbit around the sun, together with changes in the tilt of the planet’s axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary to HS-ESS2-4)*

### ESS2.A: Earth Materials and Systems

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun’s energy output or Earth’s orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4)

### ESS2.D: Weather and Climate

### Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4)

### Energy and Matter

- The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6)

### Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-ETS1-4)

### Connections to Engineering, Technology, and Applications of Science

- Influence of Science, Engineering, and Technology on Society and the Natural
The foundation for Earth’s global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy’s re-radiation into space. (HS-ESS2-4)

Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6)

Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6),(HS-ESS2-4)

**ETS1.A: Defining and Delimiting Engineering Problems**

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)

Humanity faces major global

**World**

New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3)

*Connections to Nature of Science*

**Scientific Knowledge is Based on Empirical Evidence**

Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4)
challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)

**ETS1.B: Developing Possible Solutions**

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)

**ETS1.C: Optimizing the Design Solution**
Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)

<table>
<thead>
<tr>
<th>Educational Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Operations and Concepts- Create a personal digital portfolio which reflects personal and academic interests, achievements, and career aspirations by using a variety of digital tools and resources. Produce and edit a multi-page digital document for a commercial or professional audience and present it to peers and/or professionals in that related area for review.</td>
</tr>
<tr>
<td>Creativity and Innovation- Apply previous content knowledge by creating and piloting a digital learning game or tutorial.</td>
</tr>
<tr>
<td>Communication and Collaboration- Develop an innovative solution to a real world problem or issue in collaboration with peers and experts, and present ideas for feedback through social media or in an online community.</td>
</tr>
<tr>
<td>Digital Citizenship- Demonstrate appropriate application of copyright, fair use and/or Creative Commons to an original work. Evaluate consequences of unauthorized electronic access and disclosure, and on dissemination of personal information. Compare and contrast policies on filtering and censorship both locally and globally.</td>
</tr>
<tr>
<td>Research and Information Literacy- Produce a position statement about a real world problem by developing a systematic plan of investigation with peers and experts synthesizing information from multiple sources.</td>
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<td>Critical Thinking, Problem Solving, and Decision Making- Evaluate the strengths and limitations of emerging technologies and their impact on educational, career, personal and or social needs.</td>
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Career Ready Practices

Career Ready Practices describe the career-ready skills that all educators in all content areas should seek to develop in their students. They are practices that have been linked to increase college, career, and life success. Career Ready Practices should be taught and reinforced in all career exploration and preparation programs with increasingly higher levels of complexity and expectation as a student advances through a program of study.

CRP1. Act as a responsible and contributing citizen and employee

Career-ready individuals understand the obligations and responsibilities of being a member of a community, and they demonstrate this understanding every day through their interactions with others. They are conscientious of the impacts of their decisions on others and the environment around them. They think about the near-term and long-term consequences of their actions and seek to act in ways that contribute to the betterment of their teams, families, community and workplace. They are reliable and consistent in going beyond the minimum expectation and in participating in activities that serve the greater good.

CRP2. Apply appropriate academic and technical skills.

Career-ready individuals readily access and use the knowledge and skills acquired through experience and education to be more productive. They make connections between abstract concepts with real-world applications, and they make correct insights about when it is appropriate to apply the use of an academic skill in a workplace situation.

CRP3. Attend to personal health and financial well-being.

Career-ready individuals understand the relationship between personal health, workplace performance and personal well-being; they act on that understanding to regularly practice healthy diet, exercise and mental health activities. Career-ready individuals also take regular action to contribute to their personal financial well-being, understanding that personal financial security provides the peace of mind required to contribute more fully to their own career success.

CRP4. Communicate clearly and effectively and with reason.

Career-ready individuals communicate thoughts, ideas, and action plans with clarity, whether using written, verbal, and/or visual methods. They communicate in the workplace with clarity and purpose to make maximum use of their own and others’ time. They are
excellent writers; they master conventions, word choice, and organization, and use effective tone and presentation skills to articulate ideas. They are skilled at interacting with others; they are active listeners and speak clearly and with purpose. Career-ready individuals think about the audience for their communication and prepare accordingly to ensure the desired outcome.

**CRP5. Consider the environmental, social and economic impacts of decisions.**

Career-ready individuals understand the interrelated nature of their actions and regularly make decisions that positively impact and/or mitigate negative impact on other people, organization, and the environment. They are aware of and utilize new technologies, understandings, procedures, materials, and regulations affecting the nature of their work as it relates to the impact on the social condition, the environment and the profitability of the organization.

**CRP6. Demonstrate creativity and innovation.**

Career-ready individuals regularly think of ideas that solve problems in new and different ways, and they contribute those ideas in a useful and productive manner to improve their organization. They can consider unconventional ideas and suggestions as solutions to issues, tasks or problems, and they discern which ideas and suggestions will add greatest value. They seek new methods, practices, and ideas from a variety of sources and seek to apply those ideas to their own workplace. They take action on their ideas and understand how to bring innovation to an organization.

**CRP7. Employ valid and reliable research strategies.**

Career-ready individuals are discerning in accepting and using new information to make decisions, change practices or inform strategies. They use reliable research process to search for new information. They evaluate the validity of sources when considering the use and adoption of external information or practices in their workplace situation.

**CRP8. Utilize critical thinking to make sense of problems and persevere in solving them.**

Career-ready individuals readily recognize problems in the workplace, understand the nature of the problem, and devise effective plans to solve the problem. They are aware of problems when they occur and take action quickly to address the problem; they thoughtfully investigate the root cause of the problem prior to introducing solutions. They carefully consider the options to solve the problem. Once a solution is agreed upon, they follow through to ensure the problem is solved, whether through their own actions or the actions of others.

**CRP9. Model integrity, ethical leadership and effective management.**
Career-ready individuals consistently act in ways that align personal and community-held ideals and principles while employing strategies to positively influence others in the workplace. They have a clear understanding of integrity and act on this understanding in every decision. They use a variety of means to positively impact the directions and actions of a team or organization, and they apply insights into human behavior to change others’ action, attitudes and/or beliefs. They recognize the near-term and long-term effects that management’s actions and attitudes can have on productivity, morals and organizational culture.

**CRP10. Plan education and career paths aligned to personal goals.**

Career-ready individuals take personal ownership of their own education and career goals, and they regularly act on a plan to attain these goals. They understand their own career interests, preferences, goals, and requirements. They have perspective regarding the pathways available to them and the time, effort, experience and other requirements to pursue each, including a path of entrepreneurship. They recognize the value of each step in the education and experiential process, and they recognize that nearly all career paths require ongoing education and experience. They seek counselors, mentors, and other experts to assist in the planning and execution of career and personal goals.

**CRP11. Use technology to enhance productivity.**

Career-ready individuals find and maximize the productive value of existing and new technology to accomplish workplace tasks and solve workplace problems. They are flexible and adaptive in acquiring new technology. They are proficient with ubiquitous technology applications. They understand the inherent risks-personal and organizational-of technology applications, and they take actions to prevent or mitigate these risks.

**CRP12. Work productively in teams while using cultural global competence.**

Career-ready individuals positively contribute to every team, whether formal or informal. They apply an awareness of cultural difference to avoid barriers to productive and positive interaction. They find ways to increase the engagement and contribution of all team members. They plan and facilitate effective team meetings.

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<td><strong>Suggested Field Trips</strong></td>
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<tr>
<td>The American Museum of Natural History, Lamont Doherty Earth Observatory, The New Jersey State Museum</td>
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