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 North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).]* **(HS-ESS1-5)**

(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.** *[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.]* (**HS-PS2-1**)

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. *[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.]* **(HS-ESS2-1)**

Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. *[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*

DRAFT

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.] **(HS-ESS2-3)**
(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.** *[Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]* **(HS-PS2-5)**
(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.** *[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.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]* **(HS-PS4-1)**

Quick Links		
Unit Sequence. 2	Modifications p. 8	Connections to Other Courses p. 11
What it Looks Like in the Classroom p. 4	Research on Learning p. 9	Sample Open Education Resources p. 13
Leveraging ELA/Literacy and Mathematics p. 6	Prior Learning p. 9	Appendix A: NGSS and Foundations p. 13

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

Concepts	Formative Assessment
• Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. • 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. • Change and rates of change can be quantified and modeled over very short or very long periods of time. • Some system changes are irreversible.	*Students who understand the concepts are able to:* • 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. • 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. • Quantify and model rates of change of Earth's internal and surface processes over very short and very long periods of time.

DRAFT

Part B: How much force is needed to move a continent? What can possibly provide the energy for that much force?	
Concepts	**Formative Assessment**
• 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 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.	*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 that energy drives the cycling of matter by thermal convection.

DRAFT

Part C: *Are all rocks the same age?*

Concepts	Formative Assessment
• 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. • 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. • 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.	*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 to explain the ages of crustal rocks. • Evaluate evidence of plate interactions to explain the ages of crustal rocks.

What it Looks Like in the Classroom

In this unit of study, students apply their knowledge of forces and energy as they examine Earth's dynamic and interacting systems, including the effects of feedback, and develop an understanding of plate tectonics as the unifying theory that explains the past and current movements of the rocks at Earth's surface. Plate tectonics also provides a framework for understanding Earth's geologic history. Students begin by developing models, supported by evidence, to illustrate how the Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean floor features. Students quantify and model long-term and short-term changes in the earth's crust, using examples such as continental drift, mountain building, earthquakes, and volcanic eruptions. Students construct models using drawings, clay, graham crackers, or use mathematical models or video animations to demonstrate an understanding of these concepts. Their models illustrate both constructive (deposition) and destructive (erosion) forces. Students make strategic use of digital media in presentations to enhance understanding of Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Students quantify rates of change of Earth's internal and surface processes over very short and very long periods of time. In any quantitative representations of data, students use units appropriately and consider the accuracy and limitations of any measurements. Students also appreciate that some Earth system changes are irreversible.

Evidence used to create models detail how plate movements are responsible for both continental and ocean floor features and for the distribution of rocks on the Earth's surface. Students examine maps showing the distribution of minerals or fossils to draw inferences regarding how plates have moved over time. Students interpret geological layers to describe the history of Earth events by studying geological maps, core sample data, and fossil records in order to describe and model change and rates of change of Earth events.

Further evidence of plate movement could be determined by mapping earthquakes and volcanoes to show where these types of events are more likely to occur on the Earth's surface. This activity is complemented by referencing catastrophic Earth events that occurred in the last century and throughout the history of the Earth. This shows students how certain systems are predictable over long periods of time. To determine how matter cycles in the Earth's interior, students develop an understanding of how convection cells in the mantle move thermal energy throughout the Earth and how that energy affects superficial movement of the crustal plates. Students perform experiments by creating and observing convection cells. For example, investigations include materials such as a beaker of water containing

DRAFT

pepper, raisins, glitter, or rice, placed on a hot plate. Students observe the circular motion of the particles in the water as they move upward in the convection cell over the heat source. They also observe the downward motion of the particles in other areas of the beaker. Connections are made between this type of modeling activity and convection cells in the mantle. Emphasis is placed on the importance of changing temperatures and density in these investigations so students understand the cycling of matter due to the outward flow of energy from Earth's interior and the gravitational movement of denser materials toward the interior. Further discussion of this topic emphasizes how areas of tension over thermal uprisings create divergent boundaries (rifts) and areas of compression over cooling magma create convergent boundaries (subduction zones). Students examine how transform boundaries are created between convection cells flowing in opposite directions. An understanding of the sources of thermal energy within the Earth (radioactive decay, kinetic energy transfer from asteroid collisions, and pressure due to gravity) is also important to understanding convection in the mantle. Students identify important quantities and use appropriate units when describing Earth's interior and the cycling of matter by thermal convection.

In order to develop an understanding of how current representations of the interior of the Earth were developed over time, students research the historical contributions of individuals such as Wegener (continental drift), Vine (bathymetry), and Hess (sonar and bathymetry). Students explain how changes in technology (including mapping of continental shelves, sonar, bathymetry data, high pressure laboratory experiments, and seismic monitoring stations) improved these representations. Students explain the importance of seismic waves (P-waves and S-waves) and shadow zones in understanding the interior of the Earth. Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. Students investigate and research the relative thickness, temperature, and composition of the main layers of the Earth (inner core, outer core, mantle, asthenosphere, lithosphere, and crust) and cite evidence from text to support their findings. Students create models of the interior of the Earth that describe the cycling of matter by thermal convection; these models could include paper and pencil drawings, three-dimensional clay models, or computer animations. Models demonstrate an understanding that Earth has a hot, solid inner core, a liquid outer core, and a solid mantle and crust.

Using knowledge of plate movements, students develop explanations for the ages of crustal rocks. Students begin by identifying major plates and types of boundaries using maps of the Earth's surface showing the location of major plate boundaries, such as the United States Geological Survey (USGS) plate boundary map. Students examine and evaluate evidence illustrating the following:

- Continental crust can be older than 4 billion years as compared to oceanic crust, which is less than 200 million years old, due to the subduction of oceanic crust beneath continental crust.
- The continents do not move over the ocean floor; rather, the entire plate moves over the mantle.
- Radioactive decay follows a characteristic exponential decay law and can be used to determine the ages of rocks and other materials. (Depending on where this course falls in relation to the chemistry course, students may or may not have a quantitative understanding of radioactive decay and half-lives. If this course is sequenced before chemistry, students should use only a qualitative understanding of how nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.)
- Plates moving over hot spots create island chains (e.g., Hawaiian Islands) that can be used to track plate movement.
- Magnetic field lines are formed over time due to geomagnetic reversals. These lines can be used to plot the movement of plates over time. (Data showing how magnetic field lines on the ocean floor change over time will help students appreciate the amount of time and the frequency with which reversals take place.)
- Wilson cycles (taking 500 million years each) show that the continents have separated and come together several times over Earth's history, so that the Earth's surface has reformed about eight times in our 4.5-billion-year history.

Using evidence from their research, students write informative text about the ages of crustal rocks based on past and current movements of continental and oceanic crust. Their explanations include evaluation of hypotheses, data, analysis, and conclusions, and attend to any gaps or inconsistencies. In their accounts, students

DRAFT

include narration of historical events and important scientific procedures or experiments.

(Refer to NJ High School Physics Model Curriculum Units 1, 6 and 8 for additional classroom integration ideas for the Physics Performance Expectations integrated into this unit.)

Leveraging English Language Arts/Literacy and Mathematics

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.

DRAFT

- 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.

Modifications

(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

DRAFT

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 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,

DRAFT

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

DRAFT

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 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,

DRAFT

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.

DRAFT

Samples of Open Education Resources for this Unit

(Refer to NJ High School Physics Model Curriculum Units 1, 2, 6 and 8 for additional open education resources for this unit.)

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.

Citation for research paper: Muller, R. D., M. Sdrolias, C. Gaina, and W. R. Roest (2008), Age, spreading rates, and spreading asymmetry of the world's ocean crust, Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.

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.

Citation for research paper: Poupinet, G., Shapiro, N.M., Worldwide distribution of ages of the continental lithosphere derived from a global seismic tomographic model, Lithos (2008), doi:10.1016/j.lithos.2008.10.023.

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.

DRAFT

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 North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).]* **(HS-ESS1-5)**
(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.** *[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.]* (**HS-PS2-1**)
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. *[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.]* **(HS-ESS2-1)**
Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. *[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.]* **(HS-ESS2-3)**
(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.** *[Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]* **(HS-PS2-5)**
(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.** *[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.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]* **(HS-PS4-1)**

DRAFT

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
Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-1) **Using Mathematics and Computational Thinking** • Use mathematical representations of phenomena to describe explanations. (HS-PS4-1) **Planning and Carrying Out Investigations** • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS2-5) **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) **Engaging in Argument from Evidence** • Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-	**ESS1.C: The History of Planet Earth** • 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. (HS-ESS1-5) **ESS2.A: Earth Materials and Systems** • Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-1) • 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. (HS-ESS2-3) **ESS2.B: Plate Tectonics and Large-Scale System Interactions** • 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. (ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5),(HS-ESS2-1)	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1; HS-PS2-5; HS-PS4-1) **Energy and Matter** • Energy drives the cycling of matter within and between systems. (HS-ESS2-3) **Stability and Change** • Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1) **Patterns** • Empirical evidence is needed to identify patterns. (HS-ESS1-5) - ***Connections to Engineering, Technology, and Applications of Science*** **Interdependence of Science, Engineering, and Technology** • 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. (HS-ESS2-3)

DRAFT

ESS1-5) - ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • Theories and laws provide explanations in science. (HS-PS2-1) • Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-1) **Scientific Knowledge is Based on Empirical Evidence** • Science knowledge is based on empirical evidence. (HS-ESS2-3) • Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-ESS2-3) • Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-3)	• 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) • 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. (HS-ESS2-3) **PS1.C: Nuclear Processes** • Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (secondary to HS-ESS1-5) **PS2.A: Forces and Motion** • Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1) **PS2.B: Types of Interactions** • 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. (HS-PS2-5) **PS4.A: Wave Properties** • 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. (HS-PS4-1)	

DRAFT

Embedded English Language Arts/Literacy	Mathematics
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) **RST.11-12.1** 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** 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**	Reason abstractly and quantitatively. (HS-PS2-1), (HS-PS4-1), (HS-ESS1-5), (HS-ESS2-1), (HS-ESS2-3) **MP.2** Model with mathematics. (HS-PS2-1), (HS-PS4-1), (HS-ESS2-1), (HS-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** Graph functions expressed symbolically and show key features of the graph, by in 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**

DRAFT