



Bundling Guide for Earth and Space Science

Purpose and Use

This document is intended to be a guide to provide examples of ways Performance Expectations (PEs) could be bundled. For this purpose, a bundle as defined by Pruitt (2014), is, “a set of PEs that provide students with coherent connections among concepts within and across disciplines.” This document is not intended to be read from cover to cover, but to be used, when needed, to support teacher professional learning and curriculum decisions. This is not intended for student use, and thus is not written in student-friendly language. This is not a curriculum or a means to limit instruction in the classroom. The bundles presented in this guide are not ordered for instruction. Although each PE states a dedicated Science and Engineering Practice (SEP) and Crosscutting Concept (CCC), students will need to use the whole range of SEPs and CCCs to achieve success by the end of instruction.

The bundles in this document do not represent the only way the PEs can be bundled. PEs bundled together may change depending upon the selected anchoring phenomenon that students are working to explain. The bundles presented in this guide were developed using an iterative process informed by the work of Krajick and colleagues (2014). This process is summarized in the steps below:

1. Review bundles that already exist.
2. Build bundles around an anchoring phenomenon.
 - a. The “Example anchoring phenomena to support 3D instruction” provided in this resource is just that, an example. There are myriad phenomena to support 3D instruction, and different phenomena may be more appropriate for different learning contexts.
3. Explore and look for unexpected relationships among the PEs, including bundling across disciplines (Earth and Space Science, Life Science, Physical Science) when appropriate. This can include identification of PEs that are only partially met in the bundle.
 - a. PEs within a bundle marked with an asterisk (*) share an authentic connection with the bundle but may not fully met.
 - b. PEs from additional high school content areas with a close connection to the bundle are listed. This is not intended to add to the instructional demand, but instead to provide teachers with additional content to build upon and/or support student sensemaking.
4. Make sure each PE in the grade/course is found in at least one bundle.

Stars and the Big Bang

Nuclear fusion within stars releases energy, commonly called starlight. Stars go through different stages over their lifetimes: they are formed, grow in size, mass, and brightness, and eventually burn out. The Sun is a medium-sized star about halfway through its lifespan of roughly 10 billion years. It is one of over 200 billion stars in the Milky Way galaxy, and the Milky Way is just one of hundreds of billions of galaxies in the universe. The Big Bang theory describes the formation of the universe. This theory is supported by observations of redshift and blueshift that show distant galaxies moving away from Earth, the measured composition of stars and gases, and maps of cosmic microwave background radiation. With the exception of hydrogen and helium formed during the Big Bang, nuclear fusion in stars creates all elements lighter than and including iron, releasing energy in the process. By studying the light from stars, scientists can learn about their composition, movements, and distances from Earth. This information about stars helps scientists understand the formation, age, and makeup of the universe.

PEs aligned to this bundle:

- E-ESS1-1. Develop a model based on evidence to illustrate that energy generated by nuclear fusion within the sun (and other stars) radiates to and influences orbiting planets.
- E-ESS1-2. Construct an explanation of the Big Bang Theory based on evidence to show that the universe is changing over time.
- E-ESS1-3. Construct an explanation using evidence to explain the ways elements are produced over the life cycle of a star.

Connected PEs from additional content areas:

- C-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
- C-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- C-PS4-4/P-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- P-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects.
- P-PS3-2. Develop and use models to illustrate that energy can be explained by the combination of motion and position of objects at the macroscopic scale and the motion and position of particles at the microscopic scale.

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- P-PS4-3. Evaluate the claims, evidence, and reasoning about how electromagnetic radiation can be described either by a wave model or a particle model, and in some situations one model is more useful than the other.

Example anchoring phenomena to support 3D instruction:

- H-R Diagram
- Parallax
- Stellar Life Cycles

Orbits and Gravity

Kepler's laws describe how objects in space move in predictable ways, including their elliptical orbits around the Sun. Orbits can change due to gravitational interactions or collisions with other objects in the solar system. Changes in Earth's orbit and the tilt of its axis, occurring over tens of thousands of years, affect the intensity and distribution of sunlight on Earth. These changes lead to cycles of ice ages and other gradual climate changes that can be tracked throughout geologic time. Our solar system consists of the Sun and various objects like planets, moons, asteroids, and comets. It formed from a disk of dust and gas pulled together by gravity about 4.6 billion years ago. Scientists study the light spectra and brightness of stars to learn about their composition, movements, and distances from Earth.

PEs aligned to this bundle:

- E-ESS1-4. Use mathematical or computational representations to predict the motion of orbiting objects in the universe due to gravity.
- E-ESS2-4. Use a model to describe how causes of short and long-term variations in the flow of energy into and out of Earth's systems result in changes to climate.
- E-ESS1-2. Construct an explanation of the Big Bang Theory based on evidence to show that the universe is changing over time.*
- E-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.*
- E-ESS3-5. Analyze data and the results from global climate models to make an evidence-based forecast of the current rate of regional or global climate change and associated future impacts to Earth's systems.*

Connected PEs from additional content areas:

- P-PS2-1. 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.
- P-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
- P-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects.
- P-PS3-2. Develop and use models to illustrate that energy can be explained by the combination of motion and position of objects at the macroscopic scale and the motion and position of particles at the microscopic scale.



Example anchoring phenomena to support 3D instruction:

- Ice core
- Chelyabinsk Meteor
- Meteor air burst

Changes to Earth's Surface

Continental rocks can be over 4 billion years old, while ocean floor rocks are usually less than 200 million years old. Tectonic processes constantly create new ocean floor at mid-ocean ridges and destroy old ocean floor at trenches. Scientists use radioactive decay and isotopes in rocks to date rock formations and understand the geological time scale. While active geological processes have altered much of Earth's early rock record, studying extraterrestrial objects like lunar rocks, asteroids, and meteorites provides information about Earth's formation and early history. Plate tectonics theory is supported by evidence such as magnetic patterns in undersea rocks and changes in strength and location of Earth's magnetic field, explaining the movement of tectonic plates. These plates consist of the crust and the top part of the mantle called the lithosphere. The interactions of these plates shape Earth's surface, forming mountains, ocean basins, and causing earthquakes and volcanoes. For example, the North American plate has changed in size and location due to plate motions throughout Earth's 4.5-billion-year history. Plate tectonics is driven by mantle convection, powered by heat from radioactive decay within Earth's mantle, core, and residual heat from the formation of Earth. The movement of plates results in the creation and destruction of land masses, ocean basins, mountain formation, and volcanic activity. Earth's structure includes a hot, solid inner core, a liquid outer core, a semi-solid mantle, and a solid crust. Earth's processes result from energy flow and matter cycling within and among its systems. Mantle and plate motions occur primarily through thermal convection due to the outward flow of energy from Earth's interior and the gravitational movement of denser materials toward the interior.

PEs aligned to this bundle:

- E-ESS1-5. 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.
- E-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
- E-ESS2-1. Use evidence to argue how Earth's internal and external processes operate to form and modify continental and ocean-floor features throughout Earth's history.
- E-ESS2-2. Analyze data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.*
- E-ESS2-3. Develop a model based on evidence of Earth's interior that describes cycling of matter through convection processes.
- E-ESS2-7. Communicate scientific information that illustrates how Earth's systems and life on Earth change and influence each other over time.*

Connected PEs from additional content areas:

- B-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
- C-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- C-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at a bulk scale to infer the strength of various forces between particles.
- C-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
- C-PS2-6. Communicate scientific and technical information about why the molecular structure determines the functioning of designed materials.
- P-PS2-1. 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.
- P-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Example anchoring phenomena to support 3D instruction:

- Novel islands in the Japanese archipelago
- Asteroid Bennu and OSIRIS-Rex
- Snapping shrimp mutation rates and the Isthmus of Panama

Earth System Interactions

Transfers of energy and the movement of matter can cause chemical and physical changes among Earth's materials and living organisms. Solar energy is the foundation of Earth's climate systems. This energy is reflected, absorbed, stored, and redistributed among the atmosphere, ocean, and land, and then re-radiated into space. Liquid water is essential to Earth's dynamics due to its unique properties. Water can absorb, store, and release large amounts of energy as it changes state. It can transmit sunlight, expand when it freezes, dissolve and transport materials, and lower the viscosities and melting points of materials when mixed with rocks in the mantle. These properties of water affect other Earth systems, like how ice expansion contributes to rock erosion, or how the ocean's thermal capacity moderates temperature variations. Over time, plants and other organisms capture carbon dioxide and release oxygen that can gradually change the composition of the atmosphere. Human activities have increased carbon dioxide concentrations in the atmosphere, affecting the climate. Scientists use global climate models to understand past and present climate change because these changes are complex and have occurred slowly over Earth's history. While human impacts on the climate are significant, the ability to model, predict, and manage these impacts has also improved.

PEs aligned to this bundle:

- E-ESS2-2. Analyze data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
- E-ESS2-4. Use a model to describe how causes of short and long-term variations in the flow of energy into and out of Earth's systems result in changes to climate.
- E-ESS2-5. Investigate the ways that water (given its unique physical and chemical properties) impacts various Earth systems.
- E-ESS2-6. Develop a quantitative model to describe the cycling of carbon through the hydrosphere, atmosphere, geosphere, and biosphere.
- E-ESS3-5. Analyze data and the results from global climate models to make an evidence-based forecast of the current rate of regional or global climate change and associated future impacts to Earth's systems.
- E-ESS2-7. Communicate scientific information that illustrates how Earth's systems and life on Earth change and influence each other over time.*
- E-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
- E-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.*

Connected PEs from additional content areas:

- B-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
- B-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
- B-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
- C-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
- P-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the following are known: 1) the change in energy of the other component(s) and 2) the energy flowing in and out of the system.

Example anchoring phenomena to support 3D instruction:

- Solar cycles
- Ice sheet melt
- Cyanobacteria and red-banded iron

Natural Resources and Management

Resource availability has shaped the development of human societies. Producing energy and extracting resources come with costs and risks, such as economic, social, environmental, and geopolitical challenges, as well as benefits. New technologies and regulations can change these balances. Natural hazards, like earthquakes and floods, and geologic events have influenced human history by destroying cities, eroding land, changing river courses, and reducing farmland. These events have impacted human populations and migrations. As populations grow, the risks from these hazards also increase. For societies to be sustainable and for biodiversity to be preserved, natural resources must be managed responsibly. Understanding environmental problems and reaching international agreements can lead to regulations that mitigate global impacts, like acid rain and ozone depletion near Antarctica. Scientists and engineers play a crucial role in developing technologies that reduce pollution and waste and prevent ecosystem damage. While human impacts on the environment are greater than ever, the ability to model, predict, and manage these impacts has also improved. Human activities can increase the frequency and intensity of some natural hazards, which can occur locally, regionally, or globally.

PEs aligned to this bundle:

- E-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources and occurrence of natural hazards have influenced human activity.
- E-ESS3-2. Evaluate competing design solutions that address the impacts of developing, managing, and using Earth’s energy and mineral resources.
- E-ESS3-3. Use computational representation to illustrate the relationships among the management of Earth’s resources, the sustainability of human populations, and biodiversity.
- E-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
- E-ESS3-5. Analyze data and the results from global climate models to make an evidence-based forecast of the current rate of regional or global climate change and associated future impacts to Earth’s systems.*
- E-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.*

Connected PEs from additional content areas:

- B-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- B-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions but changing conditions may result in a new ecosystem.



Example anchoring phenomena to support 3D instruction:

- Types of pollution (eutrophication, thermal, point/nonpoint)
- Lithium mining
- Algal blooms

Climate Change

Impacts of climate change, like more frequent severe storms due to ocean warming, are already affecting human activities. Scientists use computer simulations and studies to learn how the ocean, atmosphere, and biosphere interact and change because of human actions. Science and engineering are vital for understanding the impacts of global climate change and making informed decisions on how to slow it down and reduce its effects on people and the planet. Climate change impacts vary, with some regions, species, and human populations being affected more than others. Science-based predictive models help anticipate long-term changes. Global climate models are essential for understanding climate change because these changes are complex and happen slowly over time. While human impacts are greater than ever, the ability to model, predict, and manage these impacts has also improved significantly.

PEs aligned to this bundle:

- E-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- E-ESS3-7. Create an argument, based on evidence that describes how changes in climate on Earth have affected human activity.
- E-ESS2-4. Use a model to describe how causes of short and long-term variations in the flow of energy into and out of Earth's systems result in changes to climate.*
- E-ESS3-3. Use computational representation to illustrate the relationships among the management of Earth's resources, the sustainability of human populations, and biodiversity.*
- E-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*
- E-ESS3-5. Analyze data and the results from global climate models to make an evidence-based forecast of the current rate of regional or global climate change and associated future impacts to Earth's systems.*

Connected PEs from additional content areas:

- B-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- B-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions but changing conditions may result in a new ecosystem.



Example anchoring phenomena to support 3D instruction:

- Changes in flooding frequency of Charleston, SC since the 1940s
- Earthship
- Increase of atmospheric river occurrences

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