Probability of Life Elsewhere - Teacher Materials

Unit 2	Earth and Space Science

The Curriculum and Instruction Department at New Visions for Public Schools develops free, full-course materials for all areas of high school science, math, ELA, and social studies, for use across our network of 80 New York City schools and beyond.

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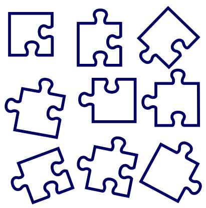
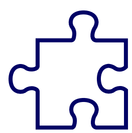
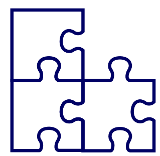
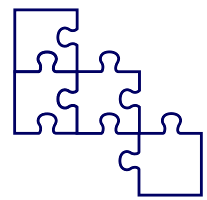
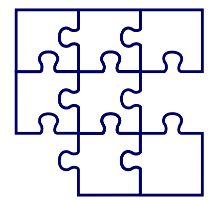
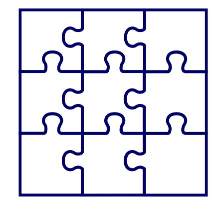
Unit 2 Probability of Life Elsewhere
Earth's History

Performance Expectations
HS-ESS1-6, HS-ESS2-5, HS-ESS2-7, HS-ESS1-2, HS-ESS1-4

Time
28-34 days

Does life exist somewhere outside Earth? What about Intelligent Life?

4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth. So far we have yet to come in contact with any other intelligent beings or even find evidence that proves any sort of life exists elsewhere. So are we alone? If not, why haven't we had contact with another intelligent species from outside planet Earth? Use your findings from research articles, data sets, and class activities to develop an explanatory model for why it took almost 4.5 billion years for modern humans to emerge on Earth, then use it to make and defend an argument about whether life or intelligent life exists somewhere outside Earth, why we have not made contact, and what humans can learn from these ideas.

Unit Opening	Stability of the Solar System 5E	Coevolution of Earth and Life 5E	Origin of the Universe 5E	Asteroid Orbits 5E	Unit Closing
Anchor Phenomenon →		**5E Lessons connect learning to the performance task** →			**Performance Task**
					
Does life exist somewhere outside Earth? What about intelligent life?	*Why do we see so many craters on other objects in our solar system, but not on Earth? What was the solar system like in the past?*	*What set of conditions allowed intelligent life to evolve from single, simple cells?*	*How many solar systems and galaxies are out there? Were they formed in the same way?*	*Will a major asteroid ever hit the Earth again? How do we know, and what can humans do to survive?*	*Does life exist somewhere outside of Earth? What about intelligent life?*

Unit Introduction

How do we make science education meaningful and relevant to our students? High school earth and space science courses are traditionally filled with lectures and cookbook labs, memorizing vocabulary, and an occasional research report. New science education standards (NGSS/NYSSLS) require a more engaging, accessible vision of science teaching and learning to help *all* students learn about the natural world and become scientifically literate citizens.

The three-dimensional, phenomenon-driven materials in this unit support students in engaging in the authentic practices of science. Students construct meaning about the natural world through modeling, investigations, labs and experiments. As students have opportunities to manipulate the physical tools of science, they also engage in productive struggle that can be resolved through creating models from evidence and engaging in consensus building discussions. The materials support teachers in becoming skillful facilitators of student sense-making and deepen teachers' understanding of how to teach science in an interactive way that is driven by students' questions and ideas.

This unit was intentionally designed to build on the first unit of this course, Discovering New Worlds, in which students generate models based on evidence. In Probability of Life Elsewhere, students continue to engage with evidence to construct scientific explanations. The common embedded group learning routines and curriculum structures introduced in the first unit are revisited, providing students and teachers multiple opportunities to engage in a culture of collaborative sensemaking around a phenomenon. In this unit, students are encouraged to explain how scientists calculate the probability of life on other planets by understanding the unique conditions of Earth that cultivated the evolution of complex life over billions of years.

The embedded group learning routines and formative assessments found in each of the Earth and Space Science units support teachers in learning about their students, both academically and personally. Whether students had strong science programs prior in prior courses, of if three-dimensional teaching and learning is brand new to them (or the teacher!), this unit is designed to reinforce and further build on students' earlier experiences with three-dimensional learning.

Unit Coherence

In Unit 2, the overall question about what conditions allowed for the evolution of complex life is intended to motivate student engagement across the unit. From the students' perspective, there should be a clear and explicit unit storyline that guides the sequence of activities. Rather than one long continuous unit, we have chosen to use an instructional model to develop four coherent sequences of lessons within Unit 2. Each sequence is based on students' questions and builds towards figuring out something that contributes to the overall unit-level question about what made Earth suitable for the evolution of complex life. This in turn allows students to explain how scientists can look for other celestial bodies that fit these parameters. The phenomena, the instructional model, and the routines embedded throughout the sequences of lessons are all used in service of coherence across Unit 2.

Phenomenon-Driven Instruction

Phenomena are a key part of instruction in A Framework for K-12 Science Education and the NGSS. As in the work of scientists, students should be encouraged to move from observable phenomena to generalizable explanations of the natural world. Too often, traditional science instruction has started with generalizable principles, sidelining the lived experience and intuitions that all young people bring to school. In this unit (and all New Visions units) there are two kinds of phenomena: anchor phenomena and investigative phenomena.

Anchor Phenomenon	Investigative Phenomena
• One per unit; drives the learning of the unit • Attention-grabbing and relevant • Does not have to be phenomenal	• One per 5E sequence (four in this unit) • Presented in the Engage phase of each 5E

Anchor Phenomenon

To support coherence, students are prompted to gure out one overarching, real-world question over the course of the unit. The anchor phenomenon question is revisited across the unit, and this question motivates the investigations conducted in each of the 5E instructional sequences. A good anchor phenomenon should be attention-grabbing and relevant to students but also thought-provoking, comprehensible, and connected to the science learning goals. It needs to be observable to students through firsthand experiences or through someone else's experiences, such as through a video or secondary data. If a teacher feels the anchor phenomenon will not be familiar or accessible to all students, we suggest relating it to similar, more familiar phenomena. It is important to notice that the phenomenon question anchoring the unit is different from the more generalized and abstracted science question for the unit. This difference is part of what helps make the unit more student-centered, rather than teacher-centered.

Investigative Phenomena

Based on the Anchor Phenomenon and three-dimensional learning goals for students for the unit, each 5E instructional sequence has a related investigative phenomenon, typically presented in the Engage phase. This phenomenon brings students together around a shared puzzle or experience that frames the learning for that 5E sequence. Similar to the anchor phenomenon question, the questions about the investigative phenomena are intended to be specific and contextualized, rather than the traditional content questions teachers use as their lesson aims. They present what is being figured out; therefore, the scientific concepts that are in the learning goal cannot be part of the wording of the question!

Storyline and Pacing Guide

Unit Opening	Does life exist somewhere outside Earth? What about intelligent life?	**Performance Expectations**	**Anchor Phenomenon** 4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth.	**Time** 2 days

Student Questions	What Students Do	Student Ideas
These questions motivate the unit storyline. • How often have asteroids struck the Earth in the past? In what ways did they affect Earth and life? • What happens to Earth when an asteroid hits it? How does it affect life? • How many asteroids like the one that killed the dinosaurs still exist in the solar system? • Can another asteroid hit Earth in the future? • Can humans go extinct too? • What happens to the atmosphere and life on Earth when volcanic eruptions occur? • Has Earth always had an atmosphere? • How has the Earth's atmosphere changed over time and how have those changes impacted life? • How many galaxies and solar systems are there? • Are other solar systems and galaxies similar to ours? Did they form in the same way?	Students are invited to consider questions regarding the existence of life, or even intelligent life, somewhere else in the universe, then watch a video that discusses the current state of the search for life elsewhere and generate questions. They hear from NASA Astrobiologists that emphasize the importance of studying evolution of life on Earth in order to answer questions about life elsewhere, then analyze a set of resources to tell a story of evolution of intelligent life on Earth. Finally, students generate questions they want to investigate further in order to answer the question: *Does intelligent life exist somewhere other than Earth?*	*These ideas are revisited throughout the unit storyline.* • Earth is only a tiny part of the whole universe. • Currently, teams of scientists from NASA and all around the world are actively searching for signs of life somewhere else in the universe. • It is important to study the evolution of life on Earth in order to answer questions about life elsewhere. • The presence of water, composition of a planet, and biosignatures give us a good idea about whether it's possible for a planet to sustain life, but many things can get in the way of life evolving. • It took about 4.5 billion years for intelligent life (humans) to evolve on Earth. • Earth has changed over the past 4.5 billion years, partially due to feedback mechanisms between Earth's systems and life as it evolved • The stability of Earth has likely been critical in allowing life to evolve • Humans are the only species on Earth with technology that makes it possible to communicate with or travel to places beyond our planet. • We can use tecno signatures (ex. Radio waves and lasers) to detect signals from intelligent life, although those signals are likely to be delayed decades because of how far they have to travel through space. • We should investigate further to learn more about the evolution of life on Earth in order to answer questions about life elsewhere.

One of the categories from the driving question board is about the number of asteroids that have hit Earth in the past and how they may have affected the evolution of life. Use these questions to transition to the next investigation about the stability of the solar system.

Stability of the Solar System 5E	Why do we see so many craters on other objects in our solar system, but not on Earth? What was the solar system like in the past?	**Performance Expectations** HS-ESS1-6, HS-ESS2-5	**Investigative Phenomenon** On Earth, the number of impact craters discovered is around 128. On Mars, the number is more than 300,000. On the Moon, the number is more than one million!	**Time** 7-8 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • Why don't we see so many craters on Earth? • Are the Earth, Moon, and Mars made of different materials? • How long ago did planets and moons in the solar system form? Did they all form at different times or at the same time? • Was the solar system more chaotic in the past?	Students examine images of Mars, the Moon and Earth and look for patterns in the existence of craters. Students then use their learning and what they know about natural destructive processes to construct an explanation for why we see so many craters on other solar objects and so few on Earth. Students analyze the role of the structure of water and other surface processes in these differences. Finally, students develop an explanatory model for how asteroid collisions with Earth have impacted stability of Earth's systems including life, then use it to make and defend an argument about whether life or intelligent life exists somewhere outside Earth, why we have not made contact, and what humans can learn from these ideas.	*Students figure out these ideas in this 5E sequence.* • Similarities in the age and composition of Earth, the Moon, Mars, and other solar system objects indicate these objects formed at the same time from the same disk of dust. • Craters all over terrestrial objects in the solar system are evidence for a chaotic solar system, where objects were colliding more frequently than today. • Natural processes like erosion and plate movement change Earth's surface significantly and at a faster rate than asteroids are creating craters, so that can explain why we see just 130 craters on Earth today. • Mercury, the Moon, and Mars have no tectonic plate activity and little to no atmosphere or water. Natural processes did not erode craters on these objects as much as on Earth. • A massive asteroid impact can cause a great deal of debris to go into the atmosphere, causing the Earth to cool by reflecting energy from the Sun. This can make it difficult for many species to survive, so that's why a major asteroid impact can cause a mass extinction.

One of the categories from the driving question board is about what happens to the atmosphere and life on Earth and how it has changed over time. Use these questions to transition to the next investigation about atmospheric changes.

Coevolution of Earth and Life 5E	What set of conditions allowed intelligent life to evolve from single, simple cells?	**Performance Expectations** HS-ESS2-7	**Investigative Phenomenon** After life appeared on Earth, it took 3.5 billion years for it to evolve from single, simple cells to intelligent human life.	**Time** 7-8 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. **From the Unit Launch:** • Has Earth always had an atmosphere? • How has the Earth's atmosphere changed over time and how have those changes impacted life? • What else causes significant changes to the atmosphere and life?	Students generate initial claims about how the pace of evolution changed over Earth's history and the conditions that allowed it. Then students analyze fossil and geologic evidence to construct a timeline of events, allowing them to draw connections between changes to oxygen levels, the biosphere, and Earth's other systems, including the feedback mechanisms between each. When students have established those relationships, they analyze information about mass extinction events and oxygen levels.Finally, students develop an explanation in support of the claim that life and Earth's systems coevolved over 3.5 billion years.	*Students figure out these ideas in this 5E sequence.* • When photosynthetic life evolved, it added carbon first to the oceans and then the atmosphere. As oxygen levels increased, it caused changes to geological processes, including rock formation and weathering. As oxygen levels increased, it also caused life to become more complex, as organisms could harness energy more efficiently. • These processes take time and depend on delicate feedback mechanisms between each of these spheres. • Billions of years ago Earth's atmosphere was primarily composed of gasses such as methane and ammonia, with very little oxygen. • Extinction events have caused the types of organisms present to shift, and as life recovers, plant life recovers, increasing oxygen, and facilitating the recovery of other species.

One of the categories from the driving question board is about whether there might be other Earth-like planets in the universe that could support life and this type of coevolution. . Use these questions to transition to the next investigation about the origins of the universe.

Origin of the Universe 5E	How many solar systems and galaxies are out there? Were they formed in the same way?	**Performance Expectations** HS-ESS1-2	**Investigative Phenomenon** There are more stars in the universe than there are grains of sand on Earth and scientists predict each one of those stars hosts several planets.	**Time** 6-7 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. **From Unit Launch:** • How many solar systems and galaxies are out there? • Were they formed in the same way? **Questions generated during this 5E:** • How did everything come from nothing? • How is it possible for there to be a beginning of the universe? What was happening before that? • What ideas does science have about the origin of the universe? What is the evidence?	Students develop an initial model for how all the matter in the universe came into existence and how that led to the formation of all the galaxies / solar systems. Students then analyze the spectra of light from other galaxies and notice a pattern of a “red shift” in the absorption lines of galaxy spectra as you examine galaxies further and further away. Using observations of the flow of sound and light energy waves from a simulation, students develop an explanation for the redshift noticed when observing the spectra of other galaxies. Students then develop a model of the early universe based on the fact that it has been expanding, and strengthen their claims by incorporating cosmic background microwave radiation and hydrogen / helium ratios in the universe as additional evidence. Finally, students use models for how the origin of the universe led to the formation of solar systems to make predictions about whether intelligent life exists on other planets.	*Students figure out these ideas in this 5E sequence.* • The universe started as all one incredibly hot and small mass, then suddenly expanded in all directions. • The processes that formed our galaxy and the solar systems within it, were taking place everywhere in the universe, so all those galaxies and solar systems must have many characteristics that are similar to the characteristics of our galaxy and solar system. • The universe is bigger than we can even imagine. • By investigating what it took for intelligent life to evolve on Earth, we understand that a planet has to be stable enough to support the evolution of life for maybe billions of years in order for intelligent life to evolve, which seems improbable, but the number of chances there are for this to happen across our universe makes it seem much more probable.

One of the categories from the driving question board is about if another asteroid could hit Earth in the future and if humans could go extinct too. Use these questions to transition to the next investigation about the asteroid orbits.

Asteroid Orbits 5E	Will a major asteroid ever hit the Earth again? How do we know, and what can humans do to survive?	**Performance Expectations** HS-ESS1-4	**Investigative Phenomenon** Apophis, a 300 meter wide asteroid, orbits the Sun in a path that crosses the Earth's orbit. Based on its current trajectory and speed, it is expected to cross Earth's path on April 23, 2029 at around 4:30 PM EST. It will pass so close to Earth that it will be visible without a telescope. It will be the largest asteroid to come so close in our recorded history.	**Time** 5-7 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. **From Unit Launch:** • Where do asteroids come from? • How many massive asteroids exist in the solar system? • Can another large asteroid hit the Earth in the future? **Questions generated during this 5E:** • How do we know whether an asteroid will hit us in the future? • What can we do to stop an asteroid if we predict it will hit Earth?	Students analyze solar system orbital data and explore the concept of gravity to surface important relationships between variables that influence orbital motion, then use mathematical representations of those relationships to explain why orbital motion of objects in the solar system exhibits a stable pattern that allows us to make predictions about asteroid trajectories. Finally students use Newton's law of gravitation to make predictions about how gravity from other solar system objects can change orbital motion and generate a solution for how we can stop an asteroid that we predict will hit Earth in the future.	*Students figure out these ideas in this 5E sequence.* • We can predict when the asteroid Apophis will pass by Earth using Kepler's 3rd law. • We can predict how fast it will be moving by using Kepler's 2nd law. • We can predict the trajectory / the shape of the orbit using Kepler's 1st law. • The mechanism for what we are claiming with Kepler's 2nd law is related to gravity. • All these motions have occurred in a predictable stable pattern, so we can feel pretty good about our predictions. • Gravitational force from other solar system objects can change the stable pattern of Apophis' orbital motion. • We can use our understanding of how gravity and collisions change orbits to change the trajectory of an asteroid that is predicted to hit Earth in the future.

After students have completed the performance task section for this investigation, have them complete the Final Performance Task section of the their performance task organizer, where they use the Drake equation to generate one more piece of evidence and use any evidence they have gathered from the unit to argue and counter argue about whether intelligent life exists elsewhere in the universe.

Unit Closing	Does life exist somewhere outside of Earth? What about intelligent life?	**Performance Expectations** HS-ESS1-6, HS-ESS2-7	**Anchor Phenomenon** 4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth.	**Time** 1-2 days

Student Questions	What Students Do	Student Ideas
These questions are addressed in the performance task. • What are the chances that another planet has the conditions that Earth has? • Are other planets stable enough to support life? • Can evolution happen for long enough on other planets for intelligent life to arise? • Can societies exist for long enough to overlap with ours?	Students use the Drake Equation and their learning throughout the unit to construct a final argument about the probability of life outside of Earth.	*These ideas were developed throughout the unit storyline.* • The big bang theory gives evidence that there should be many stars with similar conditions based on their orbit of a star • The stability of our solar system promoted life's evolution on Earth. Other planetary systems would also have to be stable in order to support life. • The co-evolution of Earth and Life took billions of years. • Human evolution has not been negatively impacted by an asteroid impact, but other organisms have been. On other planets, the evolution of intelligent life could be interrupted by an extinction event

Based on the investigations and learning throughout the unit, many of the questions asked by students have been answered, and they develop a final argument about the likelihood of intelligent life existing on other planets.

Unit Standards

This unit is designed to meet Next Generation Science Standards Performance Expectations. Since this unit is part of a full-year Biology course, the design includes intentional foregrounding of a limited number of Crosscutting Concepts (CCCs) and Science and Engineering Practices (SEPs). Further, since an aspect of NGSS design is connections to Common Core Math and ELA standards, these connections are highlighted in this section.

Performance Expectations

HS-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.**
Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.
Assessment Boundary: None

In NYS, the phrase "Earth's oldest minerals" has been replaced with "Earth's rocks and minerals."

HS-ESS2-5 **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).
Assessment Boundary: None

In NYS the clarification statement has been edited as follows: 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 could include stream transportation (erosion) and deposition using a stream table, infiltration and runoff by measuring permeability and porosity of different materials, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations could 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-ESS2-7 **Construct an argument based on evidence about the simultaneous coevolution 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 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.

In NYS the clarification statement has been edited as follows: 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 could include how the outgassing of water from Earth's interior caused the development of Earth's early oceans leading to the evolution of microorganisms and stromatolites; 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.

HS-ESS1-2	**Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.** Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium). Assessment Boundary: None
HS-ESS1-4	**Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.** Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons. Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.

Three-Dimensional Learning Goals in This Unit

Given the breadth of three-dimensional standards for high school Earth and Space Science, Unit 2 focuses primarily on ideas related to the history and formation of Earth and the Universe, including how water and oxygen influenced the evolution of life on Earth. These ideas fall within Core Ideas ESS1and ESS2 of the NGSS/NYSSLS, *Earth's Place in the Universe* and *Earth's Systems*. This unit also introduces students to the SEP of Constructing Explanations and Designing Solutions and has a secondary focus on the SEP of Constructing an Argument from Evidence. That is not to say that students will not engage in other SEPs throughout the lessons; however, it is important to foreground and be explicit about a limited number of practices with enough duration to see how students develop their understanding and ability to use this practice. This is important for both student and teacher learning! Similarly, the foregrounded CCC for this unit is *Stability and Change*, which fits well with our selected SEP and the understanding that the interplay of stability and change over geological history can describe how Earth has developed over 4 billion years. Two secondary CCCs for the unit, Energy and Matter and Thinking Mathematically are also useful to students as they use these ideas in two ways: (1) examining the evidence for the Big Bang Theory and (2) developing explanations for how changes in one Earth variable creates changes to another. The design of instruction across the unit supports students' three-dimensional learning and shifts classrooms to become more NGSS-aligned spaces.

Three Dimensions Foregrounded in Unit 2

This chart is a high-level summary of the foregrounded standards. For more detail about specific elements, see the section on Assessment later in this document.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying out Investigations	ESS1.A The Universe and Its Stars	Scale, Proportion, and Quantity
Using Mathematics and Computational Thinking	ESS1.B Earth and the Solar System	Energy and Matter
Constructing Explanations and Designing Solutions	ESS1.C The History of Planet Earth	Structure and Function
Engaging in Argument from Evidence	ESS2.A Earth Materials and Systems	Stability and Change
	ESS2.C The Roles of Water in Earth's Surface Processes	
	ESS2.D Weather and Climate	
	ESS2.E Biogeology	
	PS1.C Nuclear Processes	

Building on Middle School

High school science teaching necessarily builds on student learning from middle school. It is helpful to consider the middle school standards in order to enact a unit that builds on students' prior experiences. As we are in the middle of a multi-year transition, however, it is also critical to keep in mind that not all students will have experienced an NGSS-designed unit when they come to high school, so the process of building on middle school learning may be particularly complex for years to come. The following sections detail the ways in which this unit builds on middle school standards across the three dimensions.

Disciplinary Core Ideas from Middle School

ESS1.A The Universe and Its Stars

- In middle school, students learn that there are many galaxies in the universe, and that our solar system is only one of many within our galaxy, the Milky Way. This is important to know because students will be exploring the idea that other planets or celestial bodies may have conditions required to support life. Also, middle school students learn that the apparent motions of the Sun and other stars in the sky can be explained using models, which will help them as they consider asteroid motion.

ESS1.C The History of Planet Earth

- Students in middle school learn that the fossil record and rock strata are one way to examine Earth's history using relative dates. This background is important because students will use the concept of rock strata and radiometric dating to examine processes in Earth's history.

ESS2.C The Roles of Water in Earth's Surface Processes

- In middle school, students learn foundational concepts about water causing weathering and erosion, which students will revisit at the high school level to discuss the stability and change of Earth's surface over billions of years.

Crosscutting Concepts from Middle School

Stability and Change

This unit builds on the following aspects of Stability and Change in middle school:

- Middle school students learn that changes in one part of a system can impact other parts, and that change can happen quickly or over a long period of time. This unit builds on that background as students examine changes that happened gradually over Earth's history and disruptions that caused more rapid changes over shorter scales.

Science and Engineering Practices from Middle School
Constructing Explanations and Designing Solutions
- Students in middle school have experience constructing explanations using multiple lines of evidence. In this unit, students build upon that practice by adding student-generated sources of evidence from investigations in order to make a claim about the relationship between different variables.

Engaging in Argument from Evidence
- In middle school, students have experience constructing arguments supported by evidence and reasoning, as well as experience comparing and critiquing each others' arguments. In this Unit, students begin engaging with this practice at the High School level by evaluating the evidence behind arguments.

Assessment
Performance expectations (PEs) in the NGSS describe what students should know and be able to do. Unit 2 targets a bundle of five PEs taken from the first and second core ideas in high school Earth and Space Science (ESS1, ESS2); those standards are HS-ESS1-2, HS-ESS1-4, HS-ESS1-6, HS-ESS2-5, and HS-ESS2-7. This PE bundle informs the types of three-dimensional tasks in which students engage across the unit. Each sequence of lessons within the unit targets elements from one or more of the performance expectations for the unit, and the teacher has opportunities to collect evidence of student learning around these elements within that learning sequence. The unit-level Performance Task only targets a subset of three-dimensional learning goals informed by the bundled PEs for the unit. All other evidence of learning related to the other dimensions/elements in the PEs can be found within the instructional sequences. The **Teacher Materials** for each sequence of lessons includes a matrix that lists which student artifacts can provide evidence of student learning for each of three-dimensional learning goals from that sequence.

This unit was designed to support teachers in tracking student progress across the three dimensions, not for mastery within individual lessons. The targeted disciplinary core ideas (DCIs) listed below will be developed throughout the unit. While all of the science and engineering practices (SEPs) may be utilized across the unit, the three target SEPs for the unit are listed below. Similarly, many crosscutting concepts (CCCs) may be useful in making sense of the phenomena in this unit, however the foregrounded, targeted CCCs are listed below.

The following Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts are assessed throughout the unit:

	Stability of the Solar System 5E	Coevolution of Earth and Life 5E	Origin of the Universe 5E	Asteroid Orbits 5E
Planning and Carrying out Investigations	✔			
Using Mathematics and Computational Thinking	✔		✔	✔
Constructing Explanations and Designing Solutions	✔	✔	✔	✔
Engaging in Argument from Evidence		✔		
ESS1.A The Universe and Its Stars			✔	
ESS1.B Earth and the Solar System				✔
ESS1.C The History of Planet Earth	✔			
ESS2.A Earth Materials and Systems			✔	

	Stability of the Solar System 5E	Coevolution of Earth and Life 5E	Origin of the Universe 5E	Asteroid Orbits 5E
ESS2.C The Roles of Water in Earth's Surface Processes	✔			
ESS2.D Weather and Climate		✔		
ESS2.E Biogeology		✔		
PS1.C Nuclear Processes	✔			
Scale, Proportion, and Quantity				✔
Energy and Matter			✔	
Structure and Function	✔			
Stability and Change	✔	✔		

At the end of Unit 2, teachers will have evidence in student work (tasks) related to the elements listed in this table and can therefore make claims at the end of this unit related to student proficiency for all three performance expectations.

To support assessment throughout the unit, rubrics have been included in the **Student Materials** to support the Evaluate phase in every 5E instructional sequence. Teachers should customize these rubrics to support their schools' grading systems. Rubrics address both individual reflection, peer review, and the teacher's feedback. The Unit 2 Performance Task also includes a rubric, and the task can be considered a final summative assessment for the unit - we have not included a traditional "unit test" in our materials. Teachers may opt to create their final exam using their states' previous exam questions, however we believe that the formative assessment tasks embedded in the materials (such as the Looks and Listen For notes, the Explore phase summaries, and the modeling done in the Evaluate phases), along with the Performance Task can serve as sufficient evidence of what students know and can do.

Common Core State Standards (Mathematics)

Standards for Mathematical Practice

MP1 Make sense of problems and persevere in solving them.	Mathematically proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They analyze givens, constraints, relationships, and goals. They make conjectures about the form and meaning of the solution and plan a solution pathway rather than simply jumping into a solution attempt. They consider analogous problems, and try special cases and simpler forms of the original problem in order to gain insight into its solution. They monitor and evaluate their progress and change course if necessary. Older students might, depending on the context of the problem, transform algebraic expressions or change the viewing window on their graphing calculator to get the information they need. Mathematically proficient students can explain correspondences between equations, verbal descriptions, tables, and graphs or draw diagrams of important features and relationships, graph data, and search for regularity or trends. Younger students might rely on using concrete objects or pictures to help conceptualize and solve a problem. Mathematically proficient students check their answers to problems using a different method, and they continually ask themselves, "Does this make sense?" They can understand the approaches of others to solving complex problems and identify correspondences between different approaches.

MP2 Reason abstractly and quantitatively.	Mathematically proficient students make sense of the quantities and their relationships in problem situations. Students bring two complementary abilities to bear on problems involving quantitative relationships: the ability to decontextualize—to abstract a given situation and represent it symbolically and manipulate the representing symbols as if they have a life of their own, without necessarily attending to their referents—and the ability to contextualize, to pause as needed during the manipulation process in order to probe into the referents for the symbols involved. Quantitative reasoning entails habits of creating a coherent representation of the problem at hand; considering the units involved; attending to the meaning of quantities, not just how to compute them; and knowing and flexibly using different properties of operations and objects.
MP4 Model with mathematics.	Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace. In early grades, this might be as simple as writing an addition equation to describe a situation. In middle grades, a student might apply proportional reasoning to plan a school event or analyze a problem in the community. By high school, a student might use geometry to solve a design problem or use a function to describe how one quantity of interest depends on another. Mathematically proficient students who can apply what they know are comfortable making assumptions and approximations to simplify a complicated situation, realizing that these may need revision later. They are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas. They can analyze those relationships mathematically to draw conclusions. They routinely interpret their mathematical results in the context of the situation and reflect on whether the results make sense, possibly improving the model if it has not served its purpose.
MP5 Use appropriate tools strategically.	Mathematically proficient students consider the available tools when solving a mathematical problem. These tools might include pencil and paper, concrete models, a ruler, a protractor, a calculator, a spreadsheet, a computer algebra system, a statistical package, or dynamic geometry software. Proficient students are sufficiently familiar with tools appropriate for their grade or course to make sound decisions about when each of these tools might be helpful, recognizing both the insight to be gained and their limitations. For example, mathematically proficient high school students analyze graphs of functions and solutions generated using a graphing calculator. They detect possible errors by strategically using estimation and other mathematical knowledge. When making mathematical models, they know that technology can enable them to visualize the results of varying assumptions, explore consequences, and compare predictions with data. Mathematically proficient students at various grade levels are able to identify relevant external mathematical resources, such as digital content located on a website, and use them to pose or solve problems. They are able to use technological tools to explore and deepen their understanding of concepts.
MP6 Attend to precision.	Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. In the elementary grades, students give carefully formulated explanations to each other. By the time they reach high school they have learned to examine claims and make explicit use of definitions.
MP7 Look for and make use of structure.	Mathematically proficient students look closely to discern a pattern or structure. Young students, for example, might notice that three and seven more is the same amount as seven and three more, or they may sort a collection of shapes according to how many sides the shapes have. Later, students will see 7 × 8 equals the well remembered 7 × 5 + 7 × 3, in preparation for learning about the distributive property. In the expression x^2 + 9x + 14, older students can see the 14 as 2 × 7 and the 9 as 2 + 7. They recognize the significance of an existing line in a geometric figure and can use the strategy of drawing an auxiliary line for solving problems. They also can step back for an overview and shift perspective. They can see complicated things, such as some algebraic expressions, as single objects or as being composed of several objects. For example, they can see 5 – 3(x – y)^2 as 5 minus a positive number times a square and use that to realize that its value cannot be more than 5 for any real numbers x and y.

Reading Standards for Literacy in Science and Technical Subjects

RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects

WHST.9-10.1	Write arguments focused on discipline-specific content.
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.

Common Core State Standards (ELA/Literacy)

Speaking and Listening Standards

SL.9-10.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.9-10.2	Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.
SL.9-10.4	Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.

Reading Standards for Literacy in Science and Technical Subjects

RST.9-10.1	Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
RST.9-10.2	Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
RST.9-10.3	Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
RST.9-10.4	Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.
RST.9-10.5	Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects

WHST.9-10.1	Write arguments focused on discipline-specific content.
WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
WHST.9-10.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

WHST.9-10.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
WHST.9-10.7	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.
WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.
WHST.9-10.10	Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Implementing Unit 2

This unit is designed to be the second unit of the Earth and Space Science course. We do not recommend spending more than two months on this unit, as our field testing showed that six to eight weeks is the maximum amount of time students can stay engaged with the unit-level anchor phenomenon.

Within the unit, we also suggest spending no more than two weeks on each 5E instructional sequence. It is important to trust that ideas will build over time. Part of learning to teach NGSS-designed curriculum is getting comfortable with moving on, even if not every student "gets it," with the knowledge that there are additional opportunities to revisit particular standards. See the Assessment section below for guidance on providing multiple opportunities for assessment throughout the unit.

The first time enacting any unit with students may take longer than anticipated, particularly if the pedagogical approach is significantly different from what a teacher is used to. A teacher may want to skip entire lessons or activities, or revert to more traditional approaches when it seems like time is running out. We often ask teachers to think about the best way to modify recipes. Just like when using a recipe for the first time, it's a good idea to stay as true to the materials as possible before making modifications or substitutions! As teachers become more familiar and comfortable with the instructional model, the embedded routines, and three-dimensional teaching overall, the desire to skip things will dissipate. Teachers using our curriculum over time have noticed that they are able to move a bit quicker through this and other NGSS-designed units every year!

Routines

The table below summarizes the routines embedded in this unit. The number indicates the number of times a given routine appears in a lesson.

	Unit Opening	Stability of the Solar System 5E	Coevolution of Earth and Life 5E	Origin of the Universe 5E	Asteroid Orbits 5E	Unit Closing
Class Consensus Discussion		2	1		1	
Domino Discover	1	3	3		2	
Idea Carousel		1	1		1	
Questions Only	1					
Read-Generate-Sort-Solve				1	1	
Rumors				2		
Think-Talk-Open Exchange		1				

Literacy Strategies

The table below summarizes the literacy strategies embedded in this unit. The number indicates the number of times a given strategy appears in a lesson.

	Unit Opening	Stability of the Solar System 5E	Coevolution of Earth and Life 5E	Origin of the Universe 5E	Asteroid Orbits 5E	Unit Closing
Text Annotation	1	1				

Simulations in this Unit

Lesson	Simulation Title	Source	Technical Notes	Permissions Notes
Stability of the Solar System 5E	Radioactive Dating Game - Radiometric Dating | Carbon Dating | Half Life - PhET Interactive Simulations	https://phet.colorado.edu/en/simulations/radioactive-dating-game	NA	NA

Videos in this Unit

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Opening	Alien Life: Are we About to Find it? (0-2:29)	https://www.youtube.com/watch?v=r904HcfQoqM	NA	NA
Unit Opening	What you Need to Know About Astrobiologists	https://www.youtube.com/watch?v=3HN_zx4JJfM	NA	NA
Unit Opening	The History of Life on Earth	https://www.youtube.com/watch?v=6Ojagf3S0Qo	NA	NA
Stability of the Solar System 5E	The Late Heavy Bombardment	https://www.youtube.com/watch?v=NafhLy22DJQ	NA	NA
Coevolution of Earth and Life 5E	The Role of Oxygen in Earth's History	https://ny.pbslearningmedia.org/resource/nvaearth-sci-oxygenearth/the-role-of-the-oxygen-in-earths-history-nova/nova-premium-collection/	NA	NA
Coevolution of Earth and Life 5E	That Time Oxygen Almost Killed Everything	https://www.youtube.com/watch?v=qERdL8uHSgI	NA	NA

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Origin of the Universe 5E	How Many Stars?	https://www.youtube.com/watch?v=h-5o9TEnGrE	NA	NA
Origin of the Universe 5E	Siren Doppler Effect	https://www.youtube.com/watch?v=tVcHe1rHLpg	NA	NA
Origin of the Universe 5E	Origins of the Universe 101	https://www.youtube.com/watch?v=HdPzOWlLrbE	NA	NA
Asteroid Orbits 5E	Apophis	https://www.youtube.com/watch?v=sn-XCfkjYkc	NA	NA
Asteroid Orbits 5E	Meet the NASA Scientist Who Tracks Dangerous Asteroids in Earth's Orbit	https://www.youtube.com/watch?v=eu0q0rmHOWs	NA	NA
Asteroid Orbits 5E	Rusty Schweickart: What is the Gravity Tractor Deflection Method for Deflecting NEAs	https://www.youtube.com/watch?v=OsRD2zU0aMY	NA	NA

Lab Materials in this Unit

Lesson	Lab	Materials needed (per group)
Stability of the Solar System 5E	The Role of Water Investigation Lab minutes: 45-60 minutes	❑ Two pieces of chalk or calcium carbonate tabs ❑ White vinegar ❑ Water ❑ Two clear cups ❑ Masking tape ❑ Stopwatch ❑ Goggles ❑ Forceps ❑ Electronic balance ❑ Stream table ❑ Fine sand ❑ Coarse sand ❑ Gravel ❑ Ring stand and clamp(s) ❑ Spray bottle ❑ Stream table dividers ❑ Ruler/meter stick/measuring tape ❑ 2L soda bottle with the bottom cup off and a hole in the top of a plastic cup with holes in the bottom ❑ Round object for making craters in the stream table

Other Materials in this Unit

Lesson	Materials needed
Unit Opening	❑ Post-it notes ❑ Chart paper or digital access
Stability of the Solar System 5E	❑ The Main Asteroid Belt ❑ Chart paper ❑ markers ❑ sticky notes

Lesson	Materials needed
Coevolution of Earth and Life 5E	❑ For New York State Teachers: The Geographical History of New York State from pages 6 and 7 of the ESSRT ❑ Highlighters ❑ *Printed Fossil Cards* ❑ Chart paper ❑ Markers ❑ For New York State Teachers: The Geological History of New York State from pages 6 and 7 of the ESSRT ❑ Highlighters ❑ Colored Pen ❑ *Scaffolded Explain Cards* ❑ For New York State Teachers: The Geological History of New York State from pages 6 and 7 of the ESSRT ❑ For NYS teachers: ESSRT pages 6-7 ❑ Chart paper ❑ Sticky notes ❑ Markers
Origin of the Universe 5E	❑ Sticky notes ❑ Sticky notes ❑ Model 1: Doppler Effect ❑ Model 2: Piano ❑ Model 3: Doppler Effect ❑ Model 4: Electromagnetic Spectrum ❑ Balloons ❑ Permanent markers ❑ Murmur of a Bang ❑ Chart paper ❑ Sticky notes ❑ Markers
Asteroid Orbits 5E	❑ Kepler's Second Law ❑ Gravity ❑ Gravity and Orbits
Unit Closing	❑ Driving Question Board

Teacher Materials for Unit 2

# Unit Opening	Does life exist somewhere outside Earth? What about intelligent life?	**Performance Expectations**	**Anchor Phenomenon** 4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth.	**Time** 2 days

Does life exist somewhere outside of Earth? What about intelligent life? 4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth. So far we have yet to come in contact with any other intelligent beings or even find evidence that proves any sort of life exists elsewhere. So are we alone? If not, why haven't we had contact with another intelligent species from outside planet Earth? Use your findings from research articles, data sets, and class activities to develop an explanation for why it took almost 4.5 billion years for modern humans to emerge on Earth, then use it to make and defend an argument about whether life or intelligent life exists somewhere outside Earth, why we have not made contact, and what humans can learn from these ideas.

ANCHOR PHENOMENON	Does life exist somewhere outside of Earth? What about intelligent life?	This is a topic that should incite student curiosity and wonder! By working with students to surface what they believe about life students will express both their prior knowledge and their curiosity, allowing them to engage with the unit and increasing student buy-in.
PERFORMANCE TASK	Students review the performance task.	Review the Performance Task with students.
DRIVING QUESTION BOARD	Students develop their own questions to investigate throughout the unit.	Based on ideas that have surfaced through student discussion and scientific modeling, students develop a driving question board that will drive investigations during the unit.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

Does life exist somewhere outside of Earth? What about intelligent life?

This is a topic that should incite student curiosity and wonder! By working with students to surface what they believe about life students will express both their prior knowledge and their curiosity, allowing them to engage with the unit and increasing student buy-in.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Domino Discover ❏ Questions Only	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Tell the Story	None	❏ Alien Life: Are we About to Find it? (0-2:29) ❏ What you Need to Know About Astrobiologists ❏ The History of Life on Earth

Launch

1. Present the following questions to the class and ask them to turn discuss them with a partner :
    - Have you ever wondered about whether life exists somewhere outside of Earth?
    - Do you believe life exists somewhere outside of Earth? Why?
    - Do you think we will ever find life on other planets or communicate with other intelligent life?
2. Have students share their ideas with the rest of the class with the group learning routine, **Domino Discover**. Students will have a variety of ideas. Validate all ideas as students share and let them know that these are questions NASA scientists and many others around the world are investigating right now.
3. Tell students that you are going to show a video that discusses the current state of the search for life elsewhere and answering the question: *Are we alone?*
4. Show the video, Alien Life: Are we About to Find it? from 0-2:29. The video is likely to spark a great deal of curiosity in students. Use the group learning routine, **Questions Only**, to surface student questions at this point and document them for the class.

Access for All Learners

The question of whether there is life on other planets should spark curiosity in all students. Show the video, *Alien life: are we about to find it?* to provide important context and set the stage for this fascinating investigation.

5. Reference the scientific field of Astrobiology that was mentioned in the video, Alien Life: Are we About to Find it? Tell students that you are going to show a brief video that will give them a better idea of how NASA astrobiologists are approaching the question: *Does life exist somewhere outside Earth?*.
6. Show the video, What you Need to Know About Astrobiologists
7. Tell students that as it was noted in the astrobiology video, one very important question we have to answer is what does it take for intelligent life to evolve and we can study the evolution of life on Earth and how it came to be. Let them know that they will now have the opportunity to begin to learn about this through a few texts.

Routine

The **Questions Only** routine offers students an opportunity to generate questions that can guide their investigations about a phenomenon. This is the first time this routine appears in this unit! Please read the Earth & Space Science Course Guide for detailed steps about this routine.

Telling the Story

1. Distribute each student's *Tell the Story* handout.
2. Tell students that you are going to show a video that provides a time lapsed visualization of the evolution of life on Earth. Show the video, The History of Life on Earth , while students note observations how life on Earth and Earth itself changes over time in their *Tell the Story* organizer.
3. Students read and use **text annotation** for the two texts individually, circling three details that are the most important to the phenomenon being described.
4. Students share their ideas in their group, with every individual identifying the details that they thought were important.
5. As a group, students decide which ideas they think are important, and use those ideas to write out what happened, or the story of the phenomenon.

Conferring Prompts

Confer with students as they work in groups to tell the story.
- Why do you think this detail is important?
- Did your group members and you circle the same details?
- How did you agree, as a group, to the overall story?

Performance Task

Students review the performance task.

Review the Performance Task with students.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Introduction to the Unit Performance Task ❏ Developing an Initial Explanation	None	

Introducing the Performance Task

1. Distribute the *Introduction to the Unit Performance Task* and *Developing an Initial Explanation* to the class.
2. Allow students time to read the task and ask a few clarifying questions. Respond to student clarification questions, and let them know that they will now have an opportunity to develop questions about the topic they want to investigate throughout the unit.

Surfacing Student ideas

1. Ask students to independently consider what they just learned, as well as prior knowledge, to develop an initial model for why it took so long for intelligent life to evolve on Earth.
2. Have students work with their table groups to develop an initial collaborative model for why it took so long for intelligent life to evolve on Earth.
3. Confer with students as they collaboratively develop their initial explanations, which may be in words or drawings.

Conferring Prompts

Confer with students as they work in groups to develop their initial models.

- What details from the Tell the Story resources do you think are most relevant to answering the question about why it took so long for intelligent life to evolve on Earth? Why?
- How can you represent your ideas clearly?
- How can you use words, drawings, labels, arrows, and other types of annotations to represent your ideas?

Driving Question Board

Students develop their own questions to investigate throughout the unit.

Based on ideas that have surfaced through student discussion and scientific modeling, students develop a driving question board that will drive investigations during the unit.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	None	None

Materials

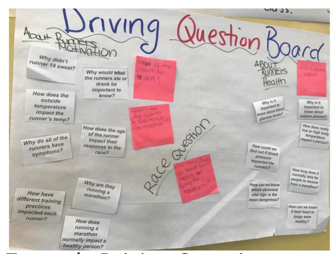
Handouts	Lab Supplies	Other Resources
None	None	❑ Post-it notes ❑ Chart paper or digital access

Developing Questions

1. At this point, students should have a lot of questions! Let them know that they will continue to investigate why it took almost 4.5 billion years for modern humans to emerge on Earth, then use it to make and defend an argument about whether life or intelligent life exists somewhere outside Earth, why we have not made contact, and what humans can learn from these ideas.

2. Individually, students come up with questions they would need to answer in order to figure out what was required for intelligent life to evolve on Earth and why did it take so long. Each question goes on a separate sticky note.

3. As a whole class or in small groups, students share and categorize their questions, as they organize the questions on chart paper.



Example Driving Question Board

Conferring Prompts

Confer with students as they create and categorize questions.

- Why do these questions belong together?
- What is the category that connects these?
- Are there other questions within this category?
- Now that you see all of your questions grouped together, do other questions come up?
- For each category, is it possible to develop an umbrella question that encompasses all of the other sub-questions in that category?

4. Let students know that they will be investigating their questions throughout the unit.

Standards in Unit Opening

Performance Expectations

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students’ own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2)		Stability and Change • Much of science deals with constructing explanations of how things change and how they remain stable. CCC7(1)

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task
Constructing Explanations and Designing Solutions		*Developing an Initial Explanation*	
Stability and Change	*Tell the Story*		

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task
Mathematics			
ELA/Literacy	RST.9-10.7 WHST.9-10.2 SL.9-10.1 SL 9-10.4	RST.9-10.1 WHST.9-10.1 WHST.9-10.5 WHST.9-10.9 SL.9-10.1 SL 9-10.4	

Stability of the Solar System 5E	Why do we see so many craters on other objects in our solar system, but not on Earth? What was the solar system like in the past?	**Performance Expectations** HS-ESS1-6, HS-ESS2-5	**Investigative Phenomenon** On Earth, the number of impact craters discovered is around 128. On Mars, the number is more than 300,000. On the Moon, the number is more than one million!	**Time** 7-8 days

In this 5E instructional sequence, students are investigating their questions about how often asteroids have struck Earth in the past, how asteroid impacts affect Earth, and what the solar system was like in the past.

ENGAGE	How often have asteroids struck Earth? Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?	Looking for evidence of **stability and change** in the **solar system**, students **examine images** of **Mars, the Moon and Earth** and look for patterns in the **existence of craters** in order to **develop initial claims** for why, despite the fact that the **oldest minerals in all three locations are about the same age, there are so few craters on Earth**.
EXPLORE 1	What can the composition and age of rocks from objects in the solar system tell us about its past?	Students **collect data** related to the **age, composition and density of rocks** on the Earth, Moon, and other solar system objects in order **to make and support claims** for why **craters on other solar system objects** remain **stable and craters on Earth change**.
EXPLAIN 1	How old are the solar system and the impact craters?	Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and **scientific reasoning to explain** the age of the solar system and the timing of the great heavy bombardment despite the **changes to Earth's surface**.
EXPLORE 2	How do the properties of water affect the persistence of impact craters on Earth?	Students **plan and conduct an investigation** into the properties of water to explore how the **molecular structure of water** and its **physical and chemical properties influence the planet's dynamics** and the persistence of impact craters on Earth's surface.
EXPLAIN 2	What explains the tremendous difference in the number of craters on the Moon, Mars, and Earth?	Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and the **molecular structure of water** as they relate to **the hydrologic and geologic** cycles **to develop a model** of the **early solar system** and use what they know about **natural destructive processes** to **explain** why **craters on other solar system objects** remain **stable and craters on Earth change**.
ELABORATE	How has the Rock Cycle Impacted the Stability of Craters on Earth?	Students use their understanding of **stability and change** to **apply scientific reasoning to assess the extent to which the data support claims** about **active geological processes interrupting the record of asteroid impacts** on Earth.
EVALUATE	How might asteroid collisions affect the probability of life evolving?	Students **develop an explanatory model** for how **asteroid collisions with Earth** have impacted **stability and change** of **Earth's systems** and the role they have played in the **evolution of life on Earth**, then use it to **make and defend an argument** about whether life or intelligent life exists somewhere outside Earth.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How often have asteroids struck Earth? Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?

Looking for evidence of **stability and change** in the **solar system**, students **examine images** of **Mars, the Moon and Earth** and look for patterns in the **existence of craters** in order to **develop initial claims** for why, despite the fact that the **oldest minerals in all three locations are about the same age, there are so few craters on Earth**.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Craters in the Solar System	None	

Launch and Surfacing Student Ideas

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to asteroid impacts, such as: *How often have asteroids struck the Earth in the past?* and *Can asteroid impacts explain why it took so long for intelligent life to evolve on Earth?*
2. Use students' questions to transition to the guiding questions: *What can we learn about the history of Earth and our solar system? How frequently did asteroids hit the Earth in the past?*
3. Ask students the following questions:
    - In past science classes, in what ways have you investigated the history of Earth?
    - What can we observe and investigate on Earth and / or on other objects and planets that might provide clues about how often asteroids struck Earth in the past?

Support students in responding to these questions by encouraging them to think about what evidence of asteroid impacts exist on Earth and to consider images they have seen of the Moon and Mars and recall what they have observed in these images that might be evidence of asteroid collisions. Have a few students share their ideas.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next steps:

- I remember hearing / seeing that there are big craters on Earth that are evidence of an asteroid impact.
- When I've seen images of the Moon or Mars they both have craters on them.
- I have seen craters on the moon when it's very visible at night.
- We can investigate how many craters are in different places in our solar system including Earth.

4. Tell students that studying rocks from Earth and other solar system objects and asteroid impact craters are a couple of the ways scientists attempt to reconstruct the history of our solar system and better understand the evolution of life on Earth.

5. Let them know that they will now have a chance to conduct these types of investigations themselves in order to answer their questions about whether asteroid impacts can help explain why it took so long for life to evolve on Earth. Provide students with the handout, *Craters in the Solar System*, and ask them to work independently as they complete the See-Think-Wonder based on data and their observations of craters on Mars, the Moon, and Earth, then use these completed pages to discuss the findings from the investigation.

6. Ask groups to come up with one important idea to share with the whole class, from their See-Think-Wonder.

7. Use the group learning routine Domino Discover to surface important trends, inferences, and questions from groups' Summary sections.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next phase(s):

- There are a lot of craters all over the Moon, some on Earth, and a lot on other objects like Mars.
- The Moon has almost 10,000 times the number of craters as Earth and more than 3 times the number of craters as Mars.
- The craters on the Moon and Mars seem to be bigger and deeper.
- I think more asteroids have hit the Moon than Mars and Earth, that's why there are so many craters.
- I think maybe Mars has existed longer than the Earth and the Moon has existed longer than Earth.
- Why don't we see so many craters on Earth?
- How long ago did planets and moons in the solar system form? Did they all form at different times or at the same time?

8. Tell students that they will now have the opportunity to investigate their questions by analyzing and interpreting age and composition data from several objects in the solar system.

Explore 1

What can the composition and age of rocks from objects in the solar system tell us about its past?

Students **collect data** related to the **age, composition and density of rocks** on the Earth, Moon, and other solar system objects in order **to make and support claims** for why **craters on other solar system objects** remain **stable and craters on Earth change**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Early Solar System Investigation	None	❑ Radioactive Dating Game - Radiometric Dating | Carbon Dating | Half Life - PhET Interactive Simulations

Launch

1. Remind students about their ideas and questions regarding what the solar system was like in the past, when planets and objects formed and what they're composed of. Have a few groups share their ideas.

2. Tell students that they will first start by developing an understanding of how the composition of rocks and other matter on Earth can be used to determine the age of those rocks and matter, then they will use what they learn to determine the age of rocks from different planets objects.

Investigation: Early Solar System

1. Provide each student with the *Early Solar System Investigation* handout.

2. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Note: for New York State Teachers, the Geologically Important Radioactive Elements Used for Radiometric Dating table comes from page 15 of the ESSRT.

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

Part 1a

- What patterns do you notice in how fast Carbon-14 changed? Was it always the same?
- What patterns do you notice in how fast Uranium-238 changed? Was it always the same?
- What do you notice was different about how fast the two isotopes changed?

Part 1b

- What pattern do you notice in the age of the fossils within the same rock layer?
- What pattern do you notice in the age of objects as you go into lower rock layers?
- What do you notice about the isotope needed to age each object?

Part 2

- What do you notice about the age of minerals of different objects in the solar system?
- What does this make you think about when the Earth and other objects were formed?
- What do you notice about tectonic activity on different objects in the solar system?
- What do you notice about the existence of water and an atmosphere on different objects in the solar system?
- Do you think this might relate to the number of impact craters we observe in different objects in the solar system? If so, what? How?

Part 3.

- What do you notice about the age of the melt rocks in the moon craters?
- Do these craters make you think about the craters on Mars and Earth? What questions do you have about those craters?

Integrating Three Dimensions

In this unit students are continuing to develop proficiency with proficiency with **CCC#6 Stability and Change**, specifically the idea that much of science deals with constructing explanations of how things change and how they remain stable. The ideas about carbon-14 and uranium-238 changing to different elements are an important part of supporting students in understanding this crosscutting concept.

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence.

Look & Listen For

These observations and ideas are critical to students' success during the Explain phase:

- 50% of carbon-14 changes into nitrogen-14 about every 5700 years.
- 50% of uranium-238 changes into lead-206 about every 4.5 billion years.
- Carbon-14 changes / decays much faster.
- Fossils in lower rock layers are older than fossils in higher rock layers.
- You need different isotopes to age things that are different ages. Uranium-238 is better for older stuff because it takes longer to decay and carbon-14 is better for younger stuff because it decays faster.
- Uranium-238 works if the rocks contain Uranium-238; Carbon-14 works only for samples containing organic materials, glacial ice containing carbon dioxide, groundwater, and ocean water.
- The ages of the objects in our solar system data table fall between 4.40 and 4.59 billion years ago. They are all pretty close in age.
- I think this tells us that the solar system formed within that time frame. Earth's crust must have formed about 4.4 billion years ago
- Differences in age don't seem to explain differences in the amount of craters observed because the Moon has way more craters than Mars and Earth, but formed after Mars and around the same time as Earth.
- The age of impact melt rocks from moon craters range from 3.75 to 4.0 billion years ago.
- This makes me think that there were a lot of asteroids hitting the moon 3.75 to 4.0 billion years ago.

These questions or similar questions can be used to transition to the next phase(s):

- If Mars, Earth and the Moon were formed around the same time and they all existed when so many asteroids were impacting, why does the moon have so many more craters?
- If a huge number of asteroids were hitting the Moon 3.75 to 4.0 billion years ago, wouldn't they have hit Mars and Earth too?

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth & Space Science Course Guide for more information on this routine.

making those observations before moving on, as they will be key to success in the Explain phase that follows.

Explain 1

How old are the solar system and the impact craters?

Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and **scientific reasoning to explain** the age of the solar system and the timing of the great heavy bombardment despite the **changes to Earth's surface**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Triads	❏ Think-Talk-Open Exchange ❏ Class Consensus Discussion	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Explaining the Craters in the Inner Solar System ❏ Summary Task	None	❏ The Main Asteroid Belt ❏ The Late Heavy Bombardment

Launch

1. Remind students that during the Explore phase they figured out that the Moon, Mars, and Earth all formed around the same time, so the amount of time they have existed cannot explain the differences in the number of craters. Also highlight the impact melt rock found in or near the large majority of craters on the moon and let students know that scientists have proposed a theory about the early solar system based on this evidence.

2. Tell students they will have a chance to learn about this theory and how it would have affected the Earth and other inner solar system bodies.

Developing Models

1. Provide students with the handout: *Explaining the Craters in the Inner Solar System*. Have students work in triads to answer the 6 questions on the first page.
2. When students are done, have them turn to the short text and use the learning routine Think-Talk-Open Exchange to share their ideas about the evidence for the Late Heavy Bombardment and its possible effects on life.
3. For additional context, show the video, The Late Heavy Bombardment .
4. Ask students to work in their groups to respond to the prompt "what was the early solar system like, and what can we infer about the history of life on Earth based on that?"

Look & Listen For

These or similar questions and ideas can be used to transition to the next phase(s):

- I think that the Earth and Mars must have had a really high number of craters since they would have been hit by a lot of asteroids during the Late Heavy Bombardment.
- Why don't we have rocks from Mars that prove that?
- Where are the craters on Earth?

Integrating Three Dimensions

In this unit students are developing proficiency with the **SEP#6 Constructing Explanations & Designing Solutions**, specifically applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support an explanation or conclusion, an important element of **SEP#6 Constructing Explanations & Designing Solutions** at the high school level.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
   - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to consensus about what the early solar system was like.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

2. Select two or three student explanations to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of when the solar system formed and how asteroids impacted inner solar system bodies. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
    - Projecting using a document camera; OR
    - Copying the written explanation to be shared and passing them out to the class; OR
    - Taking a picture of each explanation and projecting them as slides.

- Proceed through the steps in the Consensus Discussion Steps.

- Before table groups confer, prompt them to consider the role of understanding stability and change in constructing an understanding of the history of our solar system. Some prompts you might provide are:
    - As we figured out details about the history of our solar system, why was it important to understand stability and change of:
        - isotopes like Carbon-14 and Uranium-238?
        - surfaces on the Moon, Mars, and Earth?
    - How has the stability of the solar system changed over time?
    - How do you think asteroid bombardments affected stability and changes to life on Earth?

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:
- The solar system and Earth formed about 4.5 billion years ago
- Evidence for the age of the solar system comes from using radiometric dating of rocks from the moon, Mars, and Earth
- The late heavy bombardment occurred about 4 billion years ago
- Evidence for the age of the bombardment comes from radiometric dating of melt rocks on the moon
- The bombardment likely affected Mars and Venus due to the presence of craters on those planets
- Because Earth is near these other celestial bodies, the late heavy bombardment likely affected it as well, even though the craters are no longer present

6. Return to student questions from the Driving Question Board about the atmosphere, such as:
    - What makes Earth different from other planets?
    - Do other planets have water? Is water needed for life?

7. Ask students if any new questions have arisen from this investigation that they'd like to add to the board, such as:
    - Why don't we have evidence of the age of the craters on Mars?
    - Why don't we have more craters on Earth?

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **SEP#6 Constructing Explanations & Designing Solutions** explicit for students by probing and elevating ideas related to applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support and explanation or conclusion. The Conferring Prompts about evaluating how well evidence supports claims can be useful here.

Integrating Three Dimensions

The Class Consensus Discussion prompts about stability and change are meant to seed the idea that much of science deals with constructing explanations of how things change and how they remain stable, an important element of **CCC#7 Stability & Change** at the high school level. This idea will help students respond to questions about why it took so long for intelligent life to evolve on Earth and the probability of intelligent life elsewhere.

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.
2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about why Earth shows differences in its craters compared to other planets and the moon, despite their shared histories.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions, to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Explore 2

How do the properties of water affect the persistence of impact craters on Earth?

Students **plan and conduct an investigation** into the properties of water to explore how the **molecular structure of water** and its **physical and chemical properties influence the planet's dynamics** and the persistence of impact craters on Earth's surface.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ The Role of Water	❏ Two pieces of chalk or calcium carbonate tabs ❏ White vinegar ❏ Water ❏ Two clear cups ❏ Masking tape ❏ Stopwatch ❏ Goggles ❏ Forceps ❏ Electronic balance ❏ Stream table ❏ Fine sand ❏ Coarse sand ❏ Gravel ❏ Ring stand and clamp(s) ❏ Spray bottle ❏ Stream table dividers ❏ Ruler/meter stick/measuring tape ❏ 2L soda bottle with the bottom cup off and a hole in the top of a plastic cup with holes in the bottom ❏ Round object for making craters in the stream table	

Launch

1. Remind students that they had left Explain 1 wondering why, if Earth experienced the Late Heavy Bombardment at the same time as the moon and Mars, there isn't evidence of craters from 4 billion years ago
2. Tell students that there are several differences between Earth and the moon and Mars. Ask students to brainstorm some ways that they think Earth might be unique.

Look & Listen For

Possible student ideas and questions:

- Earth has oxygen
- Earth has living things
- Earth has water
- Earth is the right distance from the sun for life
- Earth has tectonic activity

3. Tell students that all of the differences they raised are important, and that they have already learned about some of those differences, but haven't discussed the others. Tell them that in this case, they are going to have the opportunity to investigate how water has impacted Earth's surface to see if it helps us understand why Earth has less evidence of craters than the moon and Mars do.

Investigation: The Role of Water

1. Provide students with the handout *Early Solar System Investigation.*

2. Tell students that they will be designing and completing an investigation into the role that water plays in Earth's processes.

3. Provide students with the materials for Part 1, and have students work in groups to perform Part 1. Chemical Weathering.

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

- Can you think of any times that acidic liquid might fall on Earth, or on craters in the past?
- How do you think the chalk is similar or different from rocks on Earth?
- What do you think would happen to rocks on Earth if acid were poured on them?

4. When students are done, pause the class to discuss the effects of acid on minerals. Help students draw connections between this investigation and their questions about craters on Earth.

5. Tell students that they will be designing an experiment for Part 2 of this investigation

Integrating Three Dimensions

In this unit students are beginning to develop proficiency with proficiency with **SEP#3 Planning and Carrying Out Investigations,** specifically determining how to design an experiment aligned to the purpose of the investigation and assign appropriate parameters for the experimental design in order to collect relevant data.

6. Provide students with their options for materials, and have them work in groups to plan and design their experiments.

Implementation Tip

It may have been a while since students were tasked with designing experiments. Refer back to Unit 3, in which students designed an investigation to test the effect of surface color on the heat absorbed by the container, when they learned about albedo. Prompt students to remember the parts of an investigation, including reviewing the concepts of independent and dependent variable, hypothesis, and experimental design.

7. When students are done with their designs, check and approve them before allowing students to collect their materials and assemble their stream tables.

8. Confer with students as they complete their investigations

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:
- How is water impacting the surfaces on the stream tables?
- How are different surface types responding differently to the water?
- How does the moisture level of the surface affect its response to water?
- How do you think these processes might relate to what happened to the craters on Earth?

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.

2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Look & Listen For

Possible student ideas and questions:
- Acidic water causes chemical weathering that breaks down Earth materials, like chalk
- Water causes physical weathering and erosion
- Chemical weathering, physical weathering, and erosion could have caused craters from asteroid impacts to erode

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth & Space Science Course Guide for more information on this routine.

Explain 2

What explains the tremendous difference in the number of craters on the Moon, Mars, and Earth?

Students **use evidence** from the **age of rocks** on the **Earth, Moon, and other solar system objects** and the **molecular structure of water** as they relate to **the hydrologic and geologic** cycles **to develop a model** of the **early solar system** and use what they know about **natural destructive processes** to **explain** why **craters on other solar system objects** remain **stable and craters on Earth change**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❏ The Role of Water ❏ Summary Task	None	

Launch

1. Remind students that during the Explore 1 phase they figured out that the Moon, Mars, and Earth all formed around the same time, so the amount of time they have existed cannot explain the differences in the number of craters. Also remind students that they have already concluded that Earth likely was affected by the Late Heavy Bombardment, but we were wondering why Earth didn't have more evidence of those impact craters.

2. Ask students to reflect on the investigation they just completed. Prompt students to share how water affected surfaces and minerals in their investigations, and to hypothesize how that might have affected the stability of Earth's craters.

3. Ask students to share their ideas about why the surface of Earth looks so different compared to the moon or mars surface.

Integrating Three Dimensions

In this unit students are developing proficiency with the **CCC#6 Structure and Function** specifically connecting the molecular structure of water to its function as a solvent in the water cycle.

Look & Listen For

- I think Earth's craters could have been worn away by erosion from water
- I think Earth's craters might have been dissolved by acid in chemical weathering

Constructing Scientific Explanation

1. Provide students with the handout, *The Role of Water*. Tell students that they will now have a chance to read a text that will help them understand if processes like the ones they described can help explain the differences in the number of craters found on Earth, Mars, and the Moon.

2. Have students read the texts, *The Role of Water* and *The Presence of Water in the Inner Solar System*, annotating for information that relates to the questions: *What can help explain the differences in the number of craters on the Moon, Mars, and Earth? Would you expect Earth-like levels of weathering, erosion, and deposition on Mercury, Mars, or the moon?*
3. After students have finished reading the texts, have them turn to a partner and share the information they annotated in response to the guiding question. Then use the group learning routine, **Domino Discover**, to surface ideas from each pair.

Look & Listen For

- Mercury, Mars, and the Moon have only trace or small amounts of water.
- The structure of water helps it dissolve carbon dioxide, creating acidic rain that can cause chemical weathering on Earth like we saw in the investigation
- Water also causes erosion, which would damage craters on Earth
- Natural processes like chemical weathering and erosion from water could not have eroded, destroyed, or covered the craters on these places, explaining why we see so many more craters on their surfaces.

4. Tell students that they will now have an opportunity to use the evidence they have gathered so far to construct a scientific explanation for the difference in the number of craters that are observed on the Moon, Mars, and Earth. Remind students that an important part of constructing a strong scientific explanation is including scientific reasoning that links evidence to the claim, and that they will have an opportunity to evaluate the extent to which data and scientific reasoning support their explanations.
5. Ask students to independently write a scientific explanation in response to the question: *Why is there a tremendous difference in the number of craters found on the Moon, Mars, and Earth?* and then evaluate the extent to which data and scientific reasoning support their explanations.
6. Confer with students as they write and evaluate their explanations. .

Conferring Prompts

- Does more than one piece of evidence support the claim?
- What scientific reasoning links each piece of evidence to the claim?
- Does the way you wrote this make the link between evidence and your claim clear to someone who reads it?
- Have you included any evidence that you are struggling to link to the claim through scientific reasoning? Why?

Integrating Three Dimensions

Use the Conferring Prompts to support students' evaluation of how well the evidence supports their claims about the differences in the number of craters on the Moon, Mars, and Earth, in service of the foregrounded element of **SEP#6 Constructing Explanations & Designing Solutions**.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
    - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to consensus about what the the early solar system was like and why we see a big difference in the number of craters on the Earth compared to objects like the Moon, Mercury, and Mars.

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student explanations to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of when the solar system formed, how stable it was, and why we see differences in craters across solar system objects. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
    - Projecting using a document camera; OR
    - Copying the written explanation to be shared and passing them out to the class; OR
    - Taking a picture of each explanation and projecting them as slides.

- Proceed through the steps in the Consensus Discussion Steps.
- Before table groups confer, prompt them to consider the role of understanding stability and change in constructing an understanding of the history of our solar system. Some prompts you might provide are:
    - As we figured out details about the history of our solar system, why was it important to understand stability and change of:
        - isotopes like Carbon-14 and Uranium-238?
        - surfaces on the Moon, Mars, and Earth?
    - How has the stability of the solar system changed over time?
    - How do you think asteroid bombardments affected stability and changes to life on Earth?
    - How do you think the structure of water affected stability and changes to life on Earth?

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **SEP#6 Constructing Explanations & Designing Solutions** explicit for students by probing and elevating ideas related to applying scientific reasoning and / or models to link evidence to claims to assess the extent to which reasoning and data support and explanation or conclusion. The Conferring Prompts about evaluating how well evidence supports claims can be useful here.

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- The fact that oldest minerals on the Earth, the Moon, Mars, and other solar system objects are about the same age (~4.5 BYA) and the similarities in their composition indicate these objects formed at the same time from the same disk of dust.
- If the Moon, Mars, and other solar system objects were being bombarded by asteroids, the Earth must have been bombarded as well since it is so close to the other objects. There were a lot of collisions in the early solar system.
- The Earth is the only of the objects with craters that has a significant amount of water. These processes that water is involved in change the surface of Earth a lot, so that can explain why we see so few craters on Earth compared to other solar system objects. The moon, Mars, and Mercury do not have nearly as much water, so they are not subject to the same types of chemical weathering and erosion, leaving more of their craters intact.
- Craters all over terrestrial objects in the solar system are evidence for a chaotic solar system, where objects were colliding more frequently than today.
- Frequent asteroid impacts must have made it difficult for life to survive and evolve.

6. Return to student ideas from the beginning of the Explore 2 phase about other factors that make Earth unique, such as: :
    - Maybe only the Earth has tectonic activity
    - Maybe only the Earth has oxygen

Summary

2. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

3. The results of this task can be used to make determinations about which students need more time to engage in sense-making about the role of water in geological process on Earth and their contribution to the changes in Earth's systems.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions, to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How has the Rock Cycle Impacted the Stability of Craters on Earth?

Students use their understanding of **stability and change** to **apply scientific reasoning to assess the extent to which the data support claims** about **active geological processes interrupting the record of asteroid impacts** on Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ The Rock Cycle	None	

Text-Based Task

1. Remind students about their questions regarding the Earth's atmosphere in the past, such as: *Are there other features of Earth that make it unique compared to the other planets? Do the other planets have tectonic activity?*
2. Tell students that rocks are constantly changing on Earth, partially due to water, but also because of other processes, in what is called the Rock Cycle.
3. Provide students with the handout, *The Rock Cycle*. Have students work in pairs to complete the task. For New York State Teachers: the Rock Cycle diagram comes from page 14 of the ESSRT.

Implementation Tip

For non New York State teachers, it may be better for your classes to use a more simplified version of the rock cycle. This version is beneficial because it allows students to connect geological processes to the presence of water and tectonic activity, but may be more detailed than your class needs.

4. Have students share out their findings.

Look & Listen For

- Water can be seen in the diagram in the processes of chemical weathering, erosion, and deposition
- Deposition creates sedimentary rocks, which are layered by age, with the oldest layers on the bottom
- These layers of sedimentary rock correlate with radioactive dating, which showed older samples in deeper layers of rocks
- The rock cycle demonstrates the constantly changing nature of the Earth's surface, which demonstrates why craters from 4 billion years ago may no longer exist on Earth's surface
- The diagram shows the connection between the rock cycle and tectonic plates, the movement of which could also damage craters
- Mercury, Mars, and the moon do not have active plate tectonics, which is another reason their craters have been stable over 4 billion years

Evaluate

How might asteroid collisions affect the probability of life evolving?

Students **develop an explanatory model** for how **asteroid collisions with Earth** have impacted **stability and change** of **Earth's systems** and the role they have played in the **evolution of life on Earth**, then use it to **make and defend an argument** about whether life or intelligent life exists somewhere outside Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs ❏ Independent ❏ Table Groups	❏ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Revisiting the Performance Task: Stability of the Solar System 5E ❏ The Beginning of Life on Earth	None	❏ Chart paper ❏ markers ❏ sticky notes

Revisit the Performance Task

1. Tell students that we haven't yet connected this 5E to the idea of how life evolved on Earth and its possibility on other planets, which is our anchor phenomenon. Ask students to reflect on how they think a period of bombardment might have impacted the evolution of life.

2. Provide students with the handout *The Beginning of Life on Earth*. Have students work in pairs to date the sample using its uranium-238 content and the uranium-238 dating curve. Ask students to connect what they've learned about the stability and change of rocks on Earth to the strengths and limitations of pinpointing when life first evolved using the fossil record.

3. Have students transition to the *Revisiting the Performance Task: Stability of the Solar System 5E* to construct an explanation in defense of a given claim that life evolved on Earth after the heavy late bombardment ended.

4. Have students independently respond to the prompts in their performance task research organizer for this Stability of the Solar System 5E.

5. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop their explanations. Prompt students to return to the class wide scientific argument characteristics, posted in the room.
Suggested conferring questions:

- What evidence did you generate in this 5E sequence?
- Where did the evidence come from?
- How well does that evidence support the claim?
- What ideas or contradictory evidence weaken the claim?

6. Ask students to work in table groups to collaboratively revise their initial group explanations from the performance task launch. These should go onto new pieces of chart paper.
7. Facilitate student critique of one anothers' models through the Group Learning Routine **Idea Carousel**. Have students annotate other groups' models using post-its. Each post it should have a symbol and comment from each of the following categories:
   a. ✔ Write a check on sticky notes with comments about ideas represented in the model that resonate.
   b. ➕ Write a plus symbol on sticky notes with comments about ideas that should be added to the model.
   c. **?** Write a question mark on sticky notes with comments about ideas that you don't think are relevant to the model.
   d. **Δ** Write a delta symbol on sticky notes with comments about suggestions for how to clarify an idea or represent it more clearly.

Look & Listen For

While students are engaged in the Idea Carousel, listen for the following ideas. Where needed, discuss with groups what is coming up in their models, to ensure these points emerge in the classroom.

- The early solar system was very chaotic, with objects like young planets and asteroids colliding with each other frequently as the solar system became more stable.
- Based on radiometric dating of moon melt rock, the solar system was being bombarded by asteroids approximately 4 billion years ago
- The Earth was likely being bombarded at that time as well, although craters from that time did not survive because of the properties of water, which cause chemical and physical weathering, and because of tectonic activity, which together create the rock cycle and put the Earth in a constant state of change
- I don't think life could have evolved, definitely not intelligent life, during the Early solar system because life needs things to be pretty stable, otherwise species would just go extinct.
- Radiometric dating of the first fossil of life puts its appearance at 3.5 billion years ago, which aligns to the hypothesis that it could only appear on a stable planet
- If life had evolved earlier, though, we might not have the data due to the same processes that degraded impact craters
- For life to evolve on another planet, it would have to be in a stable solar system, where major collisions don't happen too often, so that systems on that planet don't change too much for life to survive

8. At the end of the Idea Carousel, it may be the case that some specific ideas have surfaced in some groups but not others. If that is the case, prompt those groups to share with the class. A share-out from every group, however, is not needed at this point.
9. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Revisit the Driving Question Board

1. Use the **Driving Question Board Routine** to discuss which of the class's questions have been answered.
2. Have students identify which categories or questions they have not figured out yet. Prompt students to share out these questions, and document new questions that arise based on what they have been learning.
3. Add new questions to the Driving Question Board.
4. One question category still unanswered relates to questions about how volcanic eruptions could have killed almost all the species on Earth and what caused changes to the atmosphere.
5. Let students know that in our next investigations, they will have the opportunity to see how life evolved from that first fossil to now, and consider the unique set of circumstances that allowed it to happen.

Performance Expectations

HS-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.**
Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.
Assessment Boundary: None

In NYS, the phrase "Earth's oldest minerals" has been replaced with "Earth's rocks and minerals."

HS-ESS2-5 **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).
Assessment Boundary: None

In NYS the clarification statement has been edited as follows: 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 could include stream transportation (erosion) and deposition using a stream table, infiltration and runoff by measuring permeability and porosity of different materials, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations could 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).

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
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. SEP3(2) Using Mathematics and Computational Thinking • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. SEP5(2) Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2) • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. SEP6(4)	ESS1.C The History of Planet Earth • Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. ESS1.C(2) ESS2.C The Roles of Water in Earth's Surface Processes • 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. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit Sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. ESS2.C(1) 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. PS1.C(2)	Structure and Function • The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. CCC6(2) Stability and Change • Much of science deals with constructing explanations of how things change and how they remain stable. CCC7(1)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Planning and Carrying out Investigations			*The Role of Water*		
Using Mathematics and Computational Thinking		*Early Solar System Investigation*			*Revisiting the Performance Task: Stability of the Solar System 5E*
Constructing Explanations and Designing Solutions	*Craters in the Solar System*	*Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water Summary Task*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
ESS1.C The History of Planet Earth	*Craters in the Solar System*	*Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
ESS2.C The Roles of Water in Earth's Surface Processes			*The Role of Water*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*
PS1.C Nuclear Processes		*Early Solar System Investigation* *Explaining the Craters in the Inner Solar System Summary Task*			*Revisiting the Performance Task: Stability of the Solar System 5E*
Structure and Function			*The Role of Water*		
Stability and Change	*Craters in the Solar System*	*Early Solar System Investigation* *Explaining the Craters in the Inner Solar System Summary Task*	*The Role of Water* *The Role of Water Summary Task*	*The Rock Cycle*	*Revisiting the Performance Task: Stability of the Solar System 5E*

Common Core State Standards Connections

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP4 MP5 MP7 MP1 MP2	MP2 MP5 MP6	MP1 MP7	MP1 MP2
ELA/Literacy		RST.9-10.3 RST.9-10.7 WHST.9-10.7 SL.9-10.4 WHST.9-10.8 SL.9-10.1 SL.9-10.2	RST.9-10.3 RST.9-10.7 WHST.9-10.8 SL.9-10.4 WHST.9-10.7 SL.9-10.1	RST.9-10.4 RST.9-10.5	WHST.9-10.4 WHST.9-10.5 WHST.9-10.8 WHST.9-10.10

Coevolution of Earth and Life 5E	What set of conditions allowed intelligent life to evolve from single, simple cells?	**Performance Expectations** HS-ESS2-7	**Investigative Phenomenon** After life appeared on Earth, it took 3.5 billion years for it to evolve from single, simple cells to intelligent human life.	**Time** 7-8 days

In this 5E instructional sequence, students are investigating their questions about how the conditions of Earth allowed for intelligent life to evolve, and why it took so long.

ENGAGE	How has the pace of evolution changed over the past 4 billion years?	Students **analyze evidence** of **changes in life on Earth** in order to hypothesize about causes of those changes, including **changes to the atmosphere**.
EXPLORE	What can the fossil record tell us about the evolution of living things and Earth's systems over the past 4 billion years?	Students analyze the fossil and geological records to construct a timeline of **evidence** demonstrating the **changes to life and Earth's systems** including changes to **oxygen levels throughout Earth's history and the dynamic feedbacks between life and Earth's systems**.
EXPLAIN	How did Earth's systems and living things coevolve?	Students **construct written arguments** in support of the coevolution of life and Earth's systems **using fossil evidence, geological records, and proxy data** to support the claim that **feedbacks between Earth's system and life via oxygen levels** resulted in **changes to both sets of systems** over Earth's history.
ELABORATE	How have extinction events affected the evolution of living things?	Students **construct written and oral arguments** about the role of plants after extinction events in **stabilizing oxygen levels and supporting the recovery of life and Earth's systems** after a geological disaster **changes the environment**.
EVALUATE	Why did it take so long for intelligent life to evolve on Earth?	Students apply **scientific reasoning to explain** coevolution by **linking evidence** of **Earth's atmospheric changes with dynamic feedbacks between the biosphere and Earth's other systems**, explaining the **changes in Earth's surface over 3.5 billion years**.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How has the pace of evolution changed over the past 4 billion years?

Students **analyze evidence** of **changes in life on Earth** in order to hypothesize about causes of those changes, including **changes to the atmosphere**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ The Pace of Evolution	None	❏ For New York State Teachers: The Geographical History of New York State from pages 6 and 7 of the ESSRT ❏ Highlighters

Launch and Surfacing Student Ideas

1. Engage students in a conversation about what happened they learned at the end of the last 5E about the appearance of life on Earth. Ask them how they think life evolved from that to humans today. Ask them what conditions they think might have been necessary for that evolution to occur, and how they think that might inform scientists' search for life on other planets.
2. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to how and when life evolved on Earth, and if oxygen is important for the evolution of life, such as:
   - *Has Earth always had an atmosphere?*
   - *How has the Earth's atmosphere changed over time and how have those changes impacted life?*
3. Use students' questions to transition to the guiding questions: *What evidence do we have about the evolution of life on Earth? What were the key moments or ingredients in that process?*
4. Tell students that we will now explore exactly those questions, beginning with looking at what we know about when different forms of life evolved on Earth. Provide students with the handout, *The Pace of Evolution*, and ask them to work in pairs to observe the diagram and answer the questions below. Then, have students complete the table to brainstorm their ideas for what influenced the speed of evolution on Earth.
5. Use the routine **Domino Discover** to surface initial ideas.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next phase(s):

- Evolution began 4 billion years ago
- Photosynthesis evolved about 3.5 billion years ago
- Complex cells evolved about 2 billion years ago
- Animals began appearing about 1 billion years ago
- In the last billion years, life has exploded on Earth
- Why did evolution get faster over time?
- Did oxygen play a role in evolution?
- Did water play a role in evolution?

6. For New York State Teachers, have students turn to pages 6 and 7 of the ESSRT to view the Geological History of New York State. Using one highlighter for events relating to living things and another for events relating to non-living things, have students mark on the tables the events that correspond to the events on the diagram in the Engage handout.

7. Tell students that they will now have the opportunity to investigate their questions by observing the fossil record to gain insights on how life has changed over the past 4 billion years.

Explore

What can the fossil record tell us about the evolution of living things and Earth's systems over the past 4 billion years?

Students analyze the fossil and geological records to construct a timeline of **evidence** demonstrating the **changes to life and Earth's systems** including changes to **oxygen levels throughout Earth's history and the dynamic feedbacks between life and Earth's systems**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Beginnings of Life Investigation	❏ Two iron nails ❏ Test tubes or small bottles ❏ Oil	❏ *Printed Fossil Cards* ❏ Chart paper ❏ Markers ❏ For New York State Teachers: The Geological History of New York State from pages 6 and 7 of the ESSRT ❏ Highlighters ❏ Colored Pen

Launch

1. A few days (at least 3) before beginning this phase, set up a demo with your class. Show them that you are placing two iron nails in containers. In one container, pour water to mostly submerge the nail and leave the rest open to the air. In the other container, pour water to fully submerge the nail and pour oil on top, preventing any air from reaching the nail. Tell students that they will observe what happens to the nails with and without the presence of oxygen, and we will draw conclusions about it in a few days.

2. Remind students that our focus in this unit has been about if life could exist on other planets. Tell students that in order to understand what to look for on other planets, we first need to understand how life evolved on Earth and the types of signals life has left behind.

3. Ask students the following questions:
    - In past science classes, in what ways have you investigated the history of Earth?
    - What can we observe and investigate on Earth and / or on other objects and planets that might provide clues about what has happened in Earth's past?

Look & Listen For

- We have investigated rocks and figured out their age and what is in them to understand the history of Earth.
- I know fossils show the history of living things on Earth

4. Tell students that they will first start by observing pictures of fossil samples and constructing a timeline of how life and Earth have changed over the past 4 billion years.

Investigation: Beginnings of Life

1. Provide each student with the *Beginnings of Life Investigation* handout; and provide each group with a set of Printed Fossil Cards and one or two pieces of chart paper

Implementation Tip

Students will be constructing timelines by placing the cards in order on the timeline. This can be done on a single piece of chart paper, but the cards for the past 1 billion years will be very closely packed together. If possible, give groups two pages of chart paper for their timelines to be easier to read.

The timeline cards include maps of changes in Earth's tectonic activity. These images are optional, but align to pages 6 and 7 of the ESSRT and therefore are suggested for use by New York State teachers.

2. In table groups, have students work on Part 1 of the investigation to sort the cards in order and place them along the timeline.

3. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

- What patterns do you notice about how plants, animals, and rocks change?
- How quickly did evolution happen many billions of years ago
- How quickly did evolution happen in the past billion years?
- How do you think plants influenced Earth's systems?
- How do you think Earth's systems influenced plants?
- How do you think plants influenced animals?

4. When the timelines are complete and have been checked by the teacher, pause the class to return to the iron nail demonstration, which had been set up at least 3 days prior. At this point, the nail with air will have rusted, while the nail with no air should have no rust (or very little). Prompt students to draw

Integrating Three Dimensions

In this unit students are continuing to develop proficiency with proficiency with **CCC#7 Stability and Change**, specifically the idea that much of science deals with constructing explanations of how things change and how they remain stable. The ideas about oxygen levels changing in response to biological factors and vice versa, as well as Earth's systems changing in response to oxygen levels, are an important part of supporting students in understanding this crosscutting concept.

connections between the red, precipitated rust from the nail and the iron band formations and red beds from their timelines. Help students understand that the red color in those formations only occurs when oxygen is present, and it is the same substance that they see in the water, so scientists are confident that the presence of these red formations means that oxygen must have been present during those times and not before.

5. Have students turn to Part 2 of the investigation. In this part, students will be investigating how radioactive dating can be used to assign ages to fossil and rock samples. For New York State Teachers: the chart of Geologically Important Radioactive Elements used for Radiometric Dating comes from page 15 of the ESSRT.

Implementation Tip

Part 2 has been written to attend to the New York State Earth and Space Science Reference Tables. If you are not itching in New York State, you may not need to include Part 2 in your classroom.

6. Confer with students while they work through this part of the investigation and help them make connections between radiometric dating and the geologic and fossil records.

7. When students are done with Part 2, have them turn to Part 3 to compare their timelines to the established graph of the oxygen levels in Earth's atmosphere over the past 4 billion years. Confer with students while they work

Conferring Prompts

Confer with students during the investigation. Suggested conferring questions:

- How do these changes in oxygen levels compare to the events you saw in your timeline?
- How can you explain the changes in oxygen levels using the timeline information?
- How did the changes in oxygen correlate to or cause changes in the complexity of life?

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.
2. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.
3. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence..

Look & Listen For

These observations and ideas are critical to students' success during the Explain phase:

- Photosynthetic organisms began to create oxygen about 2.7 billion years ago
- Oxygen levels are recorded by iron band formations, red beds, and other geological features
- Photosynthetic organisms increased, and oxygen levels increased around 2.2 billion years ago, resulting in increased atmospheric oxygen
- The increase in oxygen around 2.2 billion years ago allowed the evolution of more complex cells, called Eukaryotic cells, which use oxygen to harness energy
- As oxygen levels increased, so did organism complexity, creating multicellular organisms and animals that took over land
- As plant life increased on land, so did animal life

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.
5. For New York State Teachers, have students turn to pages 6 and 7 of the ESSRT to view the Geological History of New York State. Using a colored pen, have students annotate the table to include the times when oxygen was increasing or staying the same. Using the same two colored highlighters as in the explore phase, have students highlight any other events that they saw on their timelines and appear in this table. If students did not raise any connections between the movement of the tectonic plates and changes in evolution, prompt them to consider how the configuration of the planets supported or reduced plant or animal life using the captions on the tectonic plate cards.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth & Space Science Course Guide for more information on this routine.

Explain

How did Earth's systems and living things coevolve?

Students **construct written arguments** in support of the coevolution of life and Earth's systems **using fossil evidence, geological records, and proxy data** to support the claim that **feedbacks between Earth's system and life via oxygen levels** resulted in **changes to both sets of systems** over Earth's history.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs ❏ Individual	❏ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Arguing for Coevolutions of Earth and Life ❏ Summary Task	None	❏ *Scaffolded Explain Cards* ❏ For New York State Teachers: The Geological History of New York State from pages 6 and 7 of the ESSRT ❏ The Role of Oxygen in Earth's History

Launch

1. Remind students that during the Explore phase they figured out that there were patterns in how life and Earth's systems evolved, and that they seemed to influence each other.
2. Provide students with the handout *Arguing for Coevolutions of Earth and Life*. Discuss the word "coevolution" in light of their observations from the Explore phase.
3. Show the video, The Role of Oxygen in Earth's history, and ask students to record the ways in which the surface of the Earth changed following the great oxidation event. Ask students to reflect again on the word "coevolution" and the evidence they have seen for its existence.
4. Tell students that they will now begin laying out an argument in favor of the existence of coevolution of Earth's systems and life using evidence from the Explore phase and the video they just watched.

Integrating Three Dimensions

In this 5E, students are developing proficiency with the **SEP#7 Engaging in argument from evidence**, using data from multiple pieces of evidence to construct and defend a claim.

Arguing from Evidence

1. Have students work in pairs on Part 1. Evidence of Coevolution. In this section, students will be using information from the explore phase and notes from the video in order to align evidence and reasoning to each claim stated in their handouts.

Implementation Tip

If students are struggling with the evidence and reasoning, tell students that “evidence” is things they can see or directly test, which are on their timeline pictures in bold (the description of the fossil and its age). In contrast, reasoning is the connection between the evidence and the claim, which describes how the evidence supports the claim. Students use logical inferences in addition to context provided in the italicised lines of the timeline pictures for this section.

2. When students are done, have the pairs talk to each other in table groups to share their pieces of evidence and reasoning for each claim.

3. Confer with students as they work in their groups.

Conferring Prompts

- Which pieces of evidence are you choosing to support the claim?
- What scientific reasoning links each piece of evidence to the claim?
- How do these pieces of evidence causally link to each other?

Integrating Three Dimensions

Use the Conferring Prompts to support students’ evaluation of how well different pieces of evidence come together to support their claims about the coevolution of life and Earth’s systems, a key element of **SEP#7 Engaging in argument from evidence**.

Look & Listen For

Here are some examples of evidence (E) and reasoning (R) for each claim. This list is not exhaustive, and students may include additional pieces of evidence that support each claim. Students do not need to include all examples below.

Evidence for the claim: Early life forms influenced oxygen levels in the oceans

- (E) Stromatolites with evidence of performing photosynthesis appeared 2.7 billion years ago and (R) we know that photosynthesis generates oxygen
- (E) Iron Band Formations dated from 2.5 billion years ago exist (R) and were created when oxygen was present to mix with iron so oxygen must have been present at that point

Evidence and reasoning for the claim: increasing oxygen levels in the ocean and atmosphere influenced geological formations and processes, both in the ocean and on land

- (E) Iron Band Formations exist (R) and were formed by reaction with oxygen, so oxygen influenced rock formation
- (E) Red bed sedimentary rocks exist and (R) were formed by weathering and oxidation from oxygen, so oxygen influenced rock formation
- (E) Soil appeared around 400 million years ago, (R) which was formed by microbes and plants on land which depended on oxygen
- (E) Oxidized minerals like blue and green copper minerals exist (R) which were formed by oxygen reacting with metals
- (E) The ozone layer exists (R) which was created by high levels of oxygen

Evidence and reasoning for the claim: Increasing oxygen in the oceans and atmosphere influenced biological evolution in the ocean and on land

- (E) After oxygen increased 2.5 bya as shown by the banded iron formations, eukaryotic cells appeared 2.1-2.4 bya, (R) because eukaryotic cells usually use oxygen to do aerobic cellular respiration, and complex cells couldn't have evolved without efficient energy from aerobic cellular respiration
- (E) After oxygen increased 800 million years ago as shown by red beds, complex multicellular organisms evolved about 600 million years ago and animals evolved about 560 million years ago (R) because aerobic cellular respiration made it possible for more complex organisms to evolve
- (E) After plants started moving on land about 450 million years ago, animals followed about 425 million years ago (R) because increased oxygen in the air made it possible for animals to live on land
- (E) When swamps were full of plants about 300 million years ago, insects with giant bodies existed too, because (R) insects needed a lot of oxygen to get that large and the plants made a lot of oxygen

4. After their evidence has been discussed, prompt students to consider feedback mechanisms in the chain of events they are describing. Tell students that not all feedback is in "feedback loops" where the effects amplify or negate each other. Sometimes, feedback mechanisms are just a set of interactions between different systems. In this case, we are seeing interactions between the biosphere and Earth's systems that mean that as one part changes, the other changes in response, which causes further change in the first set of systems.

5. Tell students that they will now have an opportunity to use the evidence they have gathered so far to construct an argument for the coevolution of Earth's systems and life on Earth. Remind students that an important part of constructing a strong scientific argument is considering the strength of the

evidence used to support the claim, and tell students that they will also have an opportunity to consider how their evidence has been obtained and used.

6. Have students turn to Part 2. Constructing an Argument from Evidence and ask students to independently write a scientific argument in response to the claim: *The evolution of complex organisms relied on the interactions and co-evolution of the biosphere and Earth's systems* and then use the text on the following page to reflect on the quality of their evidence and its usefulness in determining correlation or causal relationships between events.

7. Tell students that they should not be using all pieces of evidence in their arguments, but should be choosing the few pieces that best support their arguments.

8. Confer with students as they write and evaluate their arguments.

Conferring Prompts

- Which pieces of evidence are you choosing to support the claim?
- What scientific reasoning links each piece of evidence to the claim?
- How do these events demonstrate feedback mechanisms between parts of the geosphere and the biosphere? Are there any other feedback mechanisms present?
- How do these pieces of evidence causally link to each other?

9. After students write their individual arguments, have them work in table groups to synthesize a single argument on chart paper. This argument can be represented in bullet points, flow charts, images, or any other format that makes sense to the groups, but groups must be able to verbally articulate their arguments.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
    - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to consensus about how Earth's systems and life informed the evolution of each other.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student arguments to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of when different changes occurred in Earth's systems and life, how those changes relate causally or correlationally to each other, how changes between those systems demonstrate feedback mechanisms, and the quality of the data used as evidence. The decision about which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
    - Projecting using a document camera; OR
    - Copying the written argument to be shared and passing them out to the class; OR
    - Taking a picture of each explanation and projecting them as slides.

4. Proceed through the steps in the Consensus Discussion Steps. Before table groups confer, prompt them to consider the following ideas
    - Where do you see feedback mechanisms in these coevolution arguments?
    - How does the planet today compare to how it was 4 billion years ago? What happened in between and why does that matter?
    - Discuss your confidence in the conclusions that we made. What factors impacted the quality of the evidence we used to support these conclusions?

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **SEP#7 Engaging in Argument from evidence** explicit for students by probing and elevating ideas related to applying multiple pieces of evidence to support claims to The Conferring Prompts about evaluating how well evidence supports claims can be useful here.

Integrating Three Dimensions

The Class Consensus Discussion prompts about stability and change are meant to seed the idea that much of science deals with constructing explanations of how things change and how they remain stable, an important element of **CCC#7 Stability & Change** at the high school level. This idea will help students respond to questions about why it took so long for intelligent life to evolve on Earth and the probability of intelligent life elsewhere.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- Over the past 4 billion years, life has changed dramatically, though the change tended to be slow and interspersed with periods of stability
- The understanding of coevolution of life and earth's systems is based on radiometric dating of fossils and rocks and logical reasoning based on our knowledge of photosynthesis, aerobic cellular respiration (how organisms harness energy using oxygen), and rock formation
- The patterns in the timeline show us that when photosynthetic organisms increase, so does the record of oxygen in rocks, and then complexity of animals increases too. This shows a feedback mechanism
- Our conclusions are only as strong as the fossil and geological records; missing or misinterpreted information will result in incomplete conclusions

6. Return to student questions from the Driving Question Board about the disruptions to evolution, such as:
   - What happens to Earth when an asteroid hits it? How does it affect life?
   - Why don't volcanic eruptions today cause mass extinctions? What was different about the volcanic eruptions that caused mass extinctions in the past?
   - What connections did volcanic eruptions have with atmospheric changes at the time of some mass extinctions?
   - Most of the changes that we described over this period of time were gradual. What do you predict would happen to life on Earth if there were sudden and significant changes to life's systems?

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about how and when the moon formed. And what that indicates about the stability of our solar system in the past.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions, to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

How have extinction events affected the evolution of living things?

Students **construct written and oral arguments** about the role of plants after extinction events in **stabilizing oxygen levels and supporting the recovery of life and Earth's systems** after a geological disaster **changes the environment**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Summary of Mass Extinction Events ❏ Mass Extinctions and Oxygen ❏ Arguing from Evidence	None	❏ For NYS teachers: ESSRT pages 6-7 ❏ That Time Oxygen Almost Killed Everything

Text-Based Task

1. Remind students about their questions regarding the Earth's atmosphere in the past, such as: *What happens to Earth when an asteroid hits it? How does it affect life? Why don't volcanic eruptions today cause mass extinctions? What was different about the volcanic eruptions that caused mass extinctions in the past?* and *What connections did volcanic eruptions have with atmospheric changes at the time of some mass extinctions?*

2. Remind students that there have been times when major extinction events have occurred, wiping out large percentages of the organisms on Earth. Tell them that these events had both negative and positive effects on life.

3. For NYS teachers, have students turn to pages 6 and 7 of their ESSRTs and highlight all of the extinction events on the pages. Ask them to look for patterns: are there any causes of the extinctions that they can see? Does tectonic activity relate to any of these events? Do they observe any shifts in organism types after extinction events?

4. Show students the That Time Oxygen Almost Killed Everything . Prompt students to discuss: how was the evolution of photosynthesis bad for organisms that already existed on Earth? How was it good for the organisms that came after its evolution?

5. Tell students that they will now have an opportunity to learn more about the other 5 major extinction events.

6. Provide students with the handouts, *Summary of Mass Extinction Events* and *Mass Extinctions and Oxygen*. Have students work in pairs to read and discuss the chart and diagram. Prompt students to discuss the question: “How did geological events impact evolutionary ones, and how did life influence the recovery from geological disasters”

7. Use **Domino Discover** to have students share out their findings.

Look & Listen For

- Major extinction events tend to include large changes in the composition of the atmosphere
- During major extinction events, large percentages of organisms die off
- After these extinction events, different organisms increase in population and take over
- The recovery from these extinction events includes the regrowth of plant species and the resultant increase in oxygen

8. When students have had time to process the new information, provide them with the handout *Arguing from Evidence* have them work individually on the Argument from Evidence.

9. Finally, have students present their arguments orally, either within table groups or to the whole class.

10. Bring the class back together for a final discussion. Ask students to think about the pace of change in Earth’s systems: how do gradual changes with periods of stability impact life on Earth compared to these moments of abrupt and dramatic change? Why does that matter?

Evaluate

Why did it take so long for intelligent life to evolve on Earth?

Students apply **scientific reasoning to explain** coevolution by **linking evidence** of **Earth's atmospheric changes with dynamic feedbacks between the biosphere and Earth's other systems**, explaining the **changes in Earth's surface over 3.5 billion years**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Individual ❏ Table Groups	❏ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Revisiting the Performance Task: Coevolution of the Earth and Life 5E	None	❏ Chart paper ❏ Sticky notes ❏ Markers

Revisit the Performance Task

1. Have students work individually on constructing their explanations in *Revisiting the Performance Task: Coevolution of the Earth and Life 5E*.

2. Confer with students as they are working.

Conferring Prompts

Confer with students as they work to develop their explanations. Prompt students to return to the class wide scientific argument characteristics, posted in the room.
Suggested conferring questions:
- What evidence did you generate in this 5E sequence?
- Where did the evidence come from?
- How well does that evidence support the claim?
- What ideas or contradictory evidence weaken the claim?

3. Ask students to work in table groups to collaboratively revise their initial group explanations from the performance task launch. These should go onto new pieces of chart paper.

4. Facilitate student critique of one anothers' models through the Group Learning Routine **Idea Carousel**. Have students annotate other groups' models using post-its. Each post it should have a symbol and comment from each of the following categories:
    a. ✔ Write a check on sticky notes with comments about ideas represented in the model that resonate.
    b. ➕ Write a plus symbol on sticky notes with comments about ideas that should be added to the model.
    c. **?** Write a question mark on sticky notes with comments about ideas that you don't think are relevant to the model.
    d. **Δ** Write a delta symbol on sticky notes with comments about suggestions for how to clarify an idea or represent it more clearly.

Look & Listen For

- It took about 3.5 billion years for organisms to evolve from single, simple cells to humans.
- When organisms change the oxygen levels, that appears in the geological record. Examples include:
    - The first photosynthetic organisms predate the first iron band patterns
    - Known cyanobacteria fossils predate the red bed sedimentary rocks
- When plants increase the amount of oxygen present, more complex life appears. Examples include:
    - After oxygen increases enough to create red bed sedimentary rocks, eukaryotic cells followed by multicellular organisms appear
    - After algae evolves, animals follow
    - When plants move to land, animals follow
    - When plants grow large and fill swamps, large animals follow
    - When oxygen is high in the past billion years, evolution happens very quickly and results in humans
- Any other planet that supports life would have to have a very unique set of features

5. At the end of the Idea Carousel, it may be the case that some specific ideas have surfaced in some groups but not others. If that is the case, prompt those groups to share with the class. A share-out from every group, however, is not needed at this point.

6. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Revisit the Driving Question Board

1. Use the **Driving Question Board Routine** to discuss which of the class's questions have been answered.

2. Have students identify which categories or questions they have not figured out yet. Prompt students to share out these questions, and document new questions that arise based on what they have been learning.

3. Add new questions to the Driving Question Board.

4. One question category still unanswered relates to questions about if life could exist on other planets, and if there are other planets like ours.

5. Let students know that they will explore these questions in their next investigation.

Standards in Coevolution of Earth and Life 5E

Performance Expectations

HS-ESS2-7 **Construct an argument based on evidence about the simultaneous coevolution 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 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.

In NYS the clarification statement has been edited as follows: 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 could include how the outgassing of water from Earth's interior caused the development of Earth's early oceans leading to the evolution of microorganisms and stromatolites; 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.

Aspects of Three-Dimensional Learning

Science and Engineering Practices

Constructing Explanations and Designing Solutions
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2)
- Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. SEP6(4)

Engaging in Argument from Evidence
- Construct, use, and/or present an oral and written argument or counter- arguments based on data and evidence. SEP7(4)

Disciplinary Core Ideas

ESS2.D Weather and Climate
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. ESS2.D(2)

ESS2.E Biogeology
- 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. ESS2.E(1)

Crosscutting Concepts

Stability and Change
- Much of science deals with constructing explanations of how things change and how they remain stable. CCC7(1)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Constructing Explanations and Designing Solutions		*Beginnings of Life Investigation*	*Arguing for Coevolutions of Earth and Life*		*Revisiting the Performance Task: Coevolution of the Earth and Life 5E*
Engaging in Argument from Evidence		*Beginnings of Life Investigation*	*Arguing for Coevolutions of Earth and Life Summary Task*	*Arguing from Evidence*	
ESS2.D Weather and Climate		*Beginnings of Life Investigation*	*Arguing for Coevolutions of Earth and Life*	*Arguing from Evidence*	*Revisiting the Performance Task: Coevolution of the Earth and Life 5E*
ESS2.E Biogeology		*Beginnings of Life Investigation*	*Arguing for Coevolutions of Earth and Life*	*Arguing from Evidence*	*Revisiting the Performance Task: Coevolution of the Earth and Life 5E*
Stability and Change	*The Pace of Evolution*	*Beginnings of Life Investigation*	*Arguing for Coevolutions of Earth and Life Summary Task*	*Arguing from Evidence*	*Revisiting the Performance Task: Coevolution of the Earth and Life 5E*

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics	MP1 MP2		MP1	RST.9-10.1 WHST.9-10.1 WHST.9-10.9	
ELA/Literacy	RST.9-10.1 RST.9-10.2		RST.9-10.1 RST.9-10.5 WHST.9-10.1 WHST.9-10.8 SL.9-10.1 SL.9-10.4		

Classroom Resources for Coevolution of Earth and Life 5E

Scaffolded Explain Cards
Printed Fossil Cards

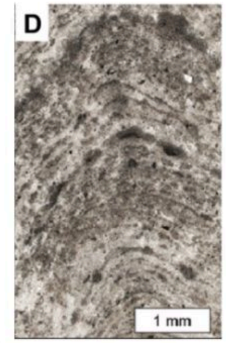
Scaffolded Explain Cards

Claim: Some simple cells evolved photosynthesis and started releasing oxygen into the ocean Evidence: Reasoning:	Claim: Oxygen in the ocean affected the rocks that formed there Evidence: Reasoning:
Claim: Oxygen in the atmosphere caused chemical weathering to increase Evidence: Reasoning:	Claim: Eventually, oxygen escaped the ocean and started moving into the atmosphere Evidence: Reasoning:
Claim: atmospheric oxygen allowed more organisms to live on land Evidence: Reasoning:	Claim: oceanic oxygen allowed more energy-efficient, larger, more complex organisms to evolve Evidence: Reasoning:
Claim: Organisms that lived on land included plants and microbes that impacted soil formation Evidence: Reasoning:	Claim: As plants became more abundant on land, animals became more abundant on land Evidence: Reasoning:

Printed Fossil Cards

Acasta Gneiss
Dated to approximately 4 billion years ago
Very rare sample of the oldest rock found on Earth

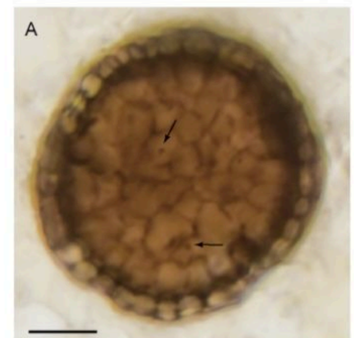
Stromatolite formation, found in the ocean
Dated to approximately 3.4 billion years ago
Characteristic striped pattern indicates mats of microscopic cells, called microbes



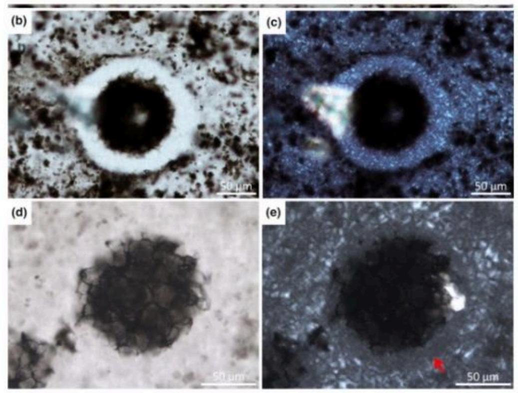
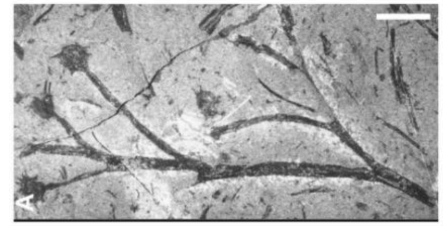
Fossils of Stromatolite Formations with evidence of photosynthesis
Dated to approximately 2.7 billion years ago
Photosynthesis is the process of using light and water to form glucose and oxygen
Light + water + carbon dioxide → glucose + oxygen

Fossil of 21 inch long dragonfly
Dated to approximately 300 million years ago
Scientists believe that the only way that insects could have been this large is if oxygen was more abundant than it is today

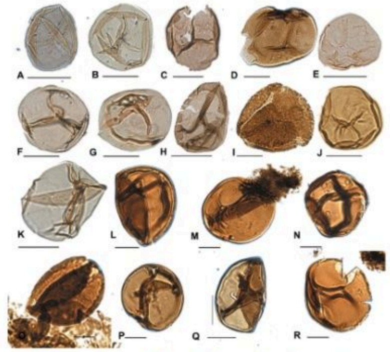
Banded Iron Formation
Dated to approximately 2.5 billion years ago
From the ocean
Red color is Iron Oxide (rust) formed by iron in the oceans mixing with oxygen
This is the first oxygen recorded in the geological record



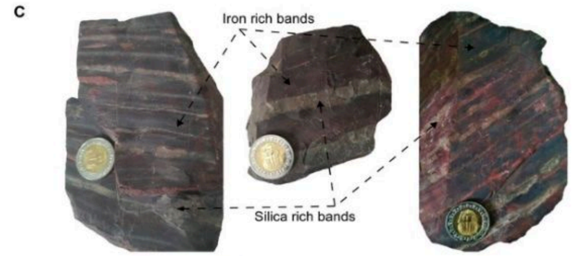
Fossils of multicellular organisms
Dated to 600 million years ago
Multicellular organisms use oxygen to perform aerobic respiration, which is a more efficient type of harnessing energy than respiration without oxygen

 **Preserved soil deposit** **Dated to approximately 407 million years ago** *Soil shows remnants of early plants that spread by spores and microbes that do cellular respiration and cycle organic matter*	 **Fossils of early Eukaryotic (complex) cells in the ocean** **Dated to approximately 2.1 billion years ago** *Eukaryotic cells use oxygen to perform aerobic respiration, which is a more efficient type of harnessing energy than respiration without oxygen*	 **Fossil of vascular plants (plants with stems)** **Dated to approximately 420 million years ago** *Plants perform photosynthesis which is the process of using light and water to form glucose and oxygen* *Light + water + carbon dioxide → glucose + oxygen*
 **Fossil of Coral Reef** **Dated to 470-548 million years ago**	 **Fossils of ocean animal diversity** **Dated to approximately 518 million years ago**	 **Red Beds of Sedimentary Rock** **Dated to approximately 2 billion years ago** *These sedimentary rocks are the result of 1. weathering from oxygen in the air, which turned particles red and crumbled them from the rock they came from, and then 2. deposition of those soils into these red beds*

Fossils of abundant plants that filled swamps
Dated to approximately 300 million years ago
Plants perform photosynthesis which is the process of using light and water to form glucose and oxygen
Light + water + carbon dioxide → glucose + oxygen

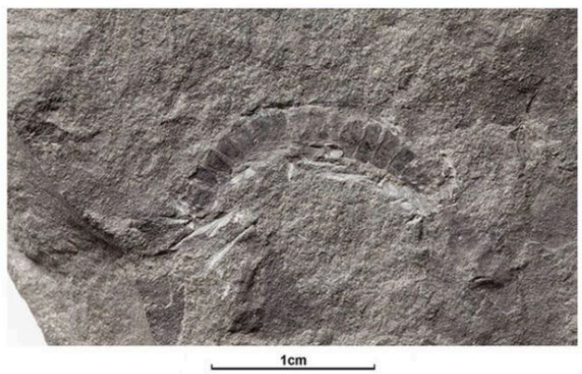


[Fossils of first land plants]()
Dated to 457-455 million years ago
Plants perform photosynthesis which is the process of using light and water to form glucose and oxygen
Light + water + carbon dioxide → glucose + oxygen



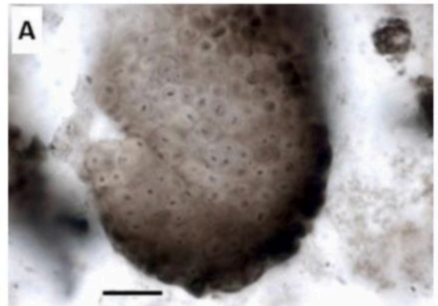
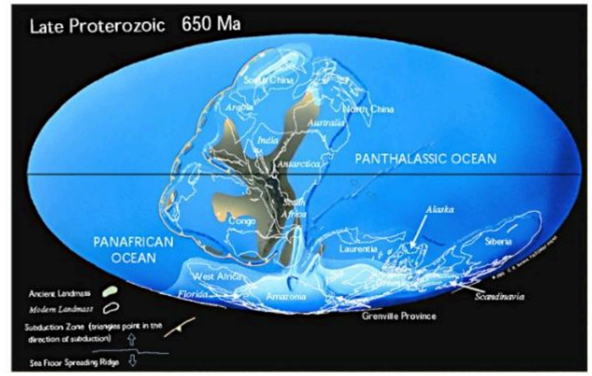
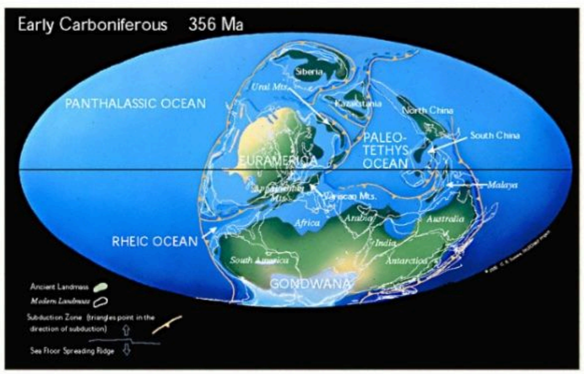
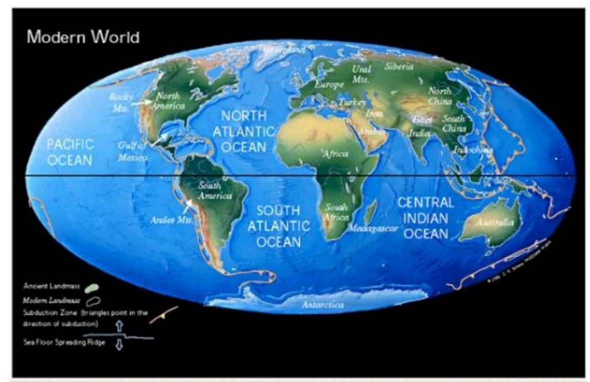
Recurrence of Banded Iron Formations Correlates to time of dramatic tectonic changes
Dated to approximately 750 million years ago
Increased erosion and sedimentation due to tectonic activity 1) increases nutrients in the ocean, increasing plant life and 2) decreases decomposition, which would otherwise absorb oxygen

Abundant Fossils of Land Animals, including arthropods, amphibians, reptiles, birds, dinosaurs, and mammals (including humans!)
Dating from 350 million years ago to present



[Oldest Fossil of Land Animal]()
Dated to approximately 425 million years ago

Fossils of the Earliest Soft Animals
Dated to approximately 560 million years ago
These animals would have used oxygen to perform efficient respiration allowing for more cells to survive and work together

 **Fossils of abundant, multicellular algae (early plants)** **From the Ocean** **Dated approximately 1 billion years ago** *Plants perform photosynthesis which is the process of using light and water to form glucose and oxygen* *Light + water + carbon dioxide → glucose + oxygen*	 **Microfossils of cyanobacteria, called *Eoentophysalis belcherensis*** **Dated to approximately 2.1 billion years ago** *First confirmed fossils of cyanobacteria cells, which perform photosynthesis* *Photosynthesis is the process of using light and water to form glucose and oxygen* *Light + water + carbon dioxide → glucose + oxygen*	 *When Rodinia broke up, it resulted in smaller continents that were more spread out*
 *Land and shallow bodies of water concentrated around the equator promoted plant growth in swamps and on land*	 *The breakup of the mega continent Rodinia around 1 billion years ago caused huge amounts of erosion and sedimentation, adding nutrients to the ocean and burying decaying matter.*	 *The current arrangement of continents supports the climate humans evolved in and the range of species that exist in different environments*

Origin of the Universe 5E	How many solar systems and galaxies are out there? Were they formed in the same way?	**Performance Expectations** HS-ESS1-2	**Investigative Phenomenon** There are more stars in the universe than there are grains of sand on Earth and scientists predict each one of those stars hosts several planets.	**Time** 6-7 days

In this 5E instructional sequence, students are investigating the questions that surfaced during the Driving Question Board launch about how many galaxies and solar systems are in the universe and whether other solar systems and galaxies are similar to ours. Students investigate electromagnetic wave behavior and use what they learn to infer that all the matter in the universe must have been tightly compacted in the beginning and then expanded. Students then use the crosscutting concept of conservation of energy to predict what evidence of a small, dense, hot universe we should be able to observe today (cosmic background radiation) and are introduced to that evidence. Students bring all this evidence together to develop an explanatory model for the origin of the universe (the big bang). Students will then connect their model of the origin of the universe to the formation of solar systems and galaxies, including our own, and use it to make claims about whether it is probable that life exists on other planets.

ENGAGE	Engage: Where did everything in the universe come from? Has the universe always been the same?	Students work in groups to **develop an initial claim** of **how the universe came into existence** and how that led to the formation of all the stars and planets.
EXPLORE	Investigating light from stars in other galaxies	Students **use a simulator** to **track the flow of** sound and light **energy waves between a source and an observer** in order to gather data that can help them explain **differences in absorption lines in spectra of light from other galaxies**.
EXPLAIN	Explaining redshift and making inferences about the universe in the past	Students use their understanding of the **flow of** sound and light **energy waves between a source and an observer** to **develop an explanation** for the **redshift** noticed when observing the **spectra of other galaxies**. Students then **develop a model** of the early universe by making inferences based on the fact that it has been expanding.
ELABORATE	Exploring additional evidence for the Big Bang theory and constructing an explanation for the origin of the universe	Students hypothesize and read a text about what the **temperature and pressure** of the **early universe** must have been like and learn about the **law of conservation of mass and energy**. Students use what they learn about the early universe and **conservation of mass and energy** to articulate why **cosmic background microwave radiation** and **Hydrogen and Helium ratios** in the universe **serve as additional evidence for their final explanatory models**.
EVALUATE	Is it probable that there is life elsewhere in the universe?	Students **use models** for **how the origin of the universe led to the formation of solar systems** to **make predictions** about whether life exists on other planets.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Engage: Where did everything in the universe come from? Has the universe always been the same?

Students work in groups to **develop an initial claim** of **how the universe came into existence** and how that led to the formation of all the stars and planets.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
❏ How did the universe form?	None	❏ Sticky notes ❏ How Many Stars?

Launch

1. Remind students that during the Driving Question Board launch, two categories of questions they had that were related to the probability of life elsewhere in the universe, were: *How many stars and planets are there in the universe?* and *Are other galaxies and solar systems similar to ours?*

2. Use these questions to transition to this 5E investigation. Tell students that you are going to show a video that will help them answer their questions about the number of stars and planets in the universe. Show the video, How Many Stars? (0-2:51 only).

3. After the video, have several students share what they took away from the video and / or reactions. Then share with students that scientists predict that each star has several planets that orbit around it.

4. Let them know that one way scientists approach investigating questions about whether stars and planets in the universe are similar to those in our solar system and galaxy, is by trying to understand how the universe formed. In other words, how the universe began and evolved into what it is today.

Surfacing Student Ideas

1. Distribute the handout, *How did the universe form?.* Tell students that you would like to hear what their ideas are about how all the matter in the universe came into existence and how that led to the formation of all the stars and planets. Have students individually respond to the following prompt:
    a. How did all the stars and planets in the universe come into existence?

2. Have students work independently to brainstorm ideas. After students have time to independently brainstorm, ask them to choose the idea they feel most confident in and write it on a post-it.

Implementation Tip

This is the first time the routine **Rumors** appears in this unit. The goal of the **Rumors** routine is to have students exchange ideas while listening for similarities and differences in thinking. It's meant to be low stakes, so it is frequently used to surface initial student ideas about phenomena during an Engage phase. Please read the Earth & Space Science Course Guide for detailed steps about this routine.

3. Use the group learning routine **Rumors** to surface students' ideas. Students may have a range of ideas, including ideas grounded in religious beliefs. Be sure to acknowledge and honor all these ideas.

4. Let students know that for the purposes of this science course, they will have an opportunity to look at the evidence scientists have gathered to answer questions about the formation of the universe to develop an explanation from a scientific perspective. Convey to students that a scientific explanation about the formation of the universe is not necessarily in contradiction with religious or philosophical beliefs, and that in fact, many scientists are also religious and often see their scientific and religious ideas about the universe as different ideas that can coexist.

Explore

Investigating light from stars in other galaxies

Students **use a simulator** to **track the flow of** sound and light **energy waves between a source and an observer** in order to gather data that can help them explain **differences in absorption lines in spectra of light from other galaxies**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	❏ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Investigating Light Spectra from Other Galaxies	None	❏ Sticky notes ❏ Model 1: Doppler Effect ❏ Model 2: Piano ❏ Model 3: Doppler Effect ❏ Model 4: Electromagnetic Spectrum ❏ Siren Doppler Effect

Launch

1. Begin by asking students to remind us what we are trying to figure out (the origin of the universe and the formation of all its stars and planets). Tell students that so far, they have a lot of ideas about where the universe came from; point to Rumors patterns if still visible in the classroom. Let them know that for the purposes of this unit's investigation, they will explore the evidence that the scientists have discovered and used to develop a theory for the origin of the universe that is widely accepted in the scientific community. Their job is to draw their own conclusions about what exactly the evidence tells us.

2. Share with students that the first piece of evidence that led to the origin of the universe theory was the discovery of other galaxies in the universe. Explain that their light absorption spectra is like the spectra from stars within our galaxy that they analyzed and interpreted during the investigation of the sun and other stars during unit 1, but it comes from the light of stars in other galaxies.

Classroom Supports

Document student questions about the spectra somewhere in the class that is visible to all, so that these questions can be revisited as students conduct the investigation that follows.

Differentiation Point

Though students have engaged with star spectra before, they may struggle to understand how light spectra form and are detected. If your classroom has access to spectroscopes, use this opportunity to explore how different colors of light result in different light spectra when viewed through the spectroscopes.

3. Distribute the handout, *Investigating Light Spectra from Other Galaxies*. Have students complete the first page of the handout and facilitate a class discussion to surface student observations.

Look & Listen For

Students may generate ideas such as:

- Like stars within our galaxy, the absorption lines from other galaxies have the same absorption pattern as hydrogen and helium gas, except they are shifted to the right / red side of the spectrum.
- There seems to be a relationship between the distance to the galaxy and the amount the absorption lines are shifted to the right / red side of the spectrum.

4. Validate these observations and ask students the following questions:
   - If the stars and galaxies are so far away, how is it possible that their light arrived here on Earth?
   - What do you think might explain the relationship between the degree to which the absorption lines are shifted right and the distance of the galaxy?

Look & Listen For

Students may generate ideas such as:

- The light travels through space from stars and galaxies.
- Something might be happening to the light when it travels here and it happens more to light from more distant galaxies because that light travels farther.

5. Ask students what they think the class should investigate in order to explain the relationship between the degree to which the absorption lines are shifted right and the distance of the galaxy. Listen for students to say that the class should study how waves travel.

6. Let them know that they will start with some scenarios here on Earth that are related, the first scenario is related to sound waves, which behave very similarly to light waves.

Investigation: Sound and Light Energy Wave Travel

1. Launch students into conducting an investigation of how sound and energy waves move between the source they are emitted from and an observer using models 1 and 2, which model the movement and properties of sound waves between a source and an observer.

Conferring Prompts

Confer with students as they work in collaborative groups to collect data and complete the See-Think-Wonder chart.
Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

Model 1
- When making observations from Model 1 what do you notice about the sound?
- What else do you notice in Model 1 that might explain the changes in the sound?
- Do you notice any differences between the sound waves as they reach the microphone when the source is moving toward the microphone and the sound waves as they reach the microphone when the source is moving away from the microphone? Why do you think this is happening?
- How does this relate to the siren sound you heard during the engage phase?

Model 2
- How do the wave characteristics change as the pitch gets higher?
- How do the wave characteristics change as the pitch gets lower?
- How does this relate to the siren sound you heard during the engage phase?

2. Have students work in lab groups to record their ideas about the data they collected from models 1 and 2 in the **See-Think-Wonder** chart.

3. Elicit student ideas through the group learning routine **Domino Discover.** Record the ideas coming up in the class on a chart paper, or on the board.

Routine

The **Domino Discover** group learning routine is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Unit 1 Teacher Guide for support with this routine.

Integrating Three Dimensions

Throughout this phase, students are engaging with **CCC #5 - Energy and Matter**. It is important that students observe that light and other forms of energy are not destroyed, but change as they move between places, objects, or systems.

Look & Listen For

These are ideas that students need to surface from the data in order to be successful with the Explain phase:

Model 1

- The sound changes as the source moves
- The sound is heard more frequently when the source is moving toward the microphone (observer)
- The sound is heard less frequently when the source is moving away from the microphone (observer)
- The sound waves are closer together in the direction that the drum is moving
- The sound waves are further apart behind the source as it moves
- I think that the microphone is picking up the sound more frequently when the source is moving toward it because the waves are bunched up and reaching it more frequently
- I think that the microphone is picking up the sound less frequently when the source is moving away from it because the waves are more spread apart and reaching it less frequently
- I think this is what was happening when the siren was moving toward and away from the observer

Model 2

- Playing different keyboard notes produces sounds with different pitches
- High frequency (low wavelength) is associated with high pitch sounds and low frequency (high wavelength) is associated with low pitch sounds
- As the wavelength of sound waves increases, the frequency decreases

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

5. Launch students into working with Models 3 and 4, and answering the corresponding questions.

Conferring Prompts

Confer with students as they work in collaborative groups to collect data and complete the See-Think-Wonder chart.
Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

Model 3

- How do the light waves change depending on the movement of the galaxy in the model?
- How do your observations of lightwaves relate to what you learned about sound waves?
- What colors does the model associate with the changes in wavelength of the light waves?

Model 4

- What is the relationship between frequency of light waves and the color an observer perceives?
- How does that relationship relate to the changes in color seen in Model 3?

6. Have students work in lab groups to record their ideas about the data in the **See-Think-Wonder** chart.
7. Elicit student ideas through the group learning routine **Domino Discover.** Record the ideas coming up in the class on a chart paper, or on the board.

Look & Listen For

These are ideas that students need to surface from the data in order to be successful with the Explain phase:

Models 3 and 4

- When the source of light and the observer are moving away from each other the light waves are perceived as having a lower frequency (longer wavelength). The observer perceives a change of light wave color toward the red side of the visible light spectrum
- When the source of light and the observer are moving toward each other the light waves are perceived as having a higher frequency (shorter wavelength). The observer perceives a change of light wave color toward the blue side of the visible light spectrum

8. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Explain

Explaining redshift and making inferences about the universe in the past

Students use their understanding of the **flow of** sound and light **energy waves between a source and an observer** to **develop an explanation** for the **redshift** noticed when observing the **spectra of other galaxies**. Students then **develop a model** of the early universe by making inferences based on the fact that it has been expanding.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Read-Generate-Sort-Solve	None

Materials

Handouts	Lab Supplies	Other Resources
❏ What does the light spectra of galaxies tell us? ❏ Summary Task	None	

Constructing an Explanation for Red Shift in Galaxy Light Spectra Data

1. Remind students that as part of their investigation to understand the scientific theory about the origin of the formation of the universe (big bang theory) they are trying to understand and explain the first piece of evidence that led scientists to their theory, the light spectra from other galaxies.

2. Distribute the handout, *What does the light spectra of galaxies tell us?*. Have students use what they learned from the Explore phase to complete predictions about what changes in light waves would be perceived as a result of different observer and source scenarios.

Implementation Tip

Many students need support to build a habit of generating many ideas before selecting the best one. The **Read-Generate-Sort-Solve** routine supports students in articulating their thinking and making it transparent, before considering solutions. Please read the Earth & Space Science Course Guide for detailed steps about this routine.

3. Facilitate student collaboration in constructing an explanation for the galaxy light spectra data, using the Group Learning Routine, Read-Generate-Sort-Solve.

4. Confer with students as they develop their explanation.

Look & Listen For

While students are engaged in Read-Generate-Sort-Solve, circulate and listen for these ideas:

- The galaxy light spectra data appears to have the absorption signature of hydrogen and helium, but shifted to the red side of the spectrum
- The galaxy light spectra data shows that the further a galaxy is the more the absorption signature of hydrogen and helium is shifted to the red side of the spectrum
- Based on our observations from model 3 from the Explore phase, I think this means the universe is expanding, causing galaxies to move further away from us.

Class Consensus Discussion

1. Orient the class to the purpose and the format of the group learning routine **Class Consensus Discussion**. You may say something like this:

"We have a lot of different ideas circulating in the room right now, and they are in the form of different scientific explanations. It is really important for us to get to some agreement on how we represent what we know about why there is a shift in the light spectra data of other galaxies when compared to the spectra of stars in our galaxy, so that we have a shared understanding to build upon as we move ahead. In order to do this we are going to do something called a **Class Consensus Discussion**. First I will select a few different groups to share their ideas. Then, we will let each group share their claim and discuss what we can agree to as a class."

You may decide to walk students through the entire poster, or take them through the steps as you facilitate it.

2. Select two or three groups' claims to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of how the Sun releases energy. The decision about which claims to share with the class should be based on both the ideas circulating in the classroom *and* the goals of this part of the 5E sequence. Look ahead to the "Take Time for these Key Points" below to help you determine which groups you want to share out, so that those key points are surfaced.

3. Ask the first group to share their claim. You can do this by:
   - Projecting using a document camera; OR
   - Copying the claims to be shared and passing them out to the class; OR
   - Taking a picture of each model and projecting them as slides.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. It provides an opportunity for groups to share out around their sensemaking and for other groups to list, summarize, and ask questions after each share. This is the first time doing such a discussion in this unit, so focus more on the *steps* and the process. In future parts of this unit, you will use this format to do more in-depth discussions and consensus building. For now, it's just about establishing a common understanding of the format.

Classroom Supports

Post the steps to the Class Consensus Discussion in the room, as a reference you can return to in future lessons.

Class Consensus Discussion Steps

- We select a few different groups' ideas.
- The first group shares out their work.
- One person repeats or reiterates what the first group shared.
- Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

- Everyone confers in table groups.
- Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

4. Proceed through the steps in the Consensus Discussion Steps.

5. Before table groups confer, prompt them to consider the role of models in figuring out which claim is best supported. These prompts connect to high school elements of CCC #4 - Systems and Systems Models and SEP #2 - Developing and Using Models. Some prompts you might provide are:
   a. What did we observe in the models 1 and 3 that was helpful in explaining the shift in spectra from different galaxies? Why?
   b. How did the models serve as evidence to support your explanation?
   c. Was the energy in the models ever destroyed? What happened to it?
   d. Where do you think the energy in the models came from?
   e. Why was it useful to use four different models during this investigation? What was most useful about each? What limitations did they each have?

Implementation Tip

We recommend you do NOT just let students read their claims aloud. Some classmates will need to see/read the claim to be able to follow up. A discussion with no visual component can leave out a number of students.

6. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk; use the guidelines below to ensure the class focuses on ideas that will drive the lesson and unit forward.

Integrating Three Dimensions

The prompts in the Class Consensus Discussion are in support of students' consideration of the foregrounded SEP and CCC. The first two questions is meant to surface the idea that models can be used as evidence, an important high school element of **SEP #6 - Constructing Explanations and Designing Solutions.**
The next set of prompts surfaces the idea that these models are showing the movement of energy, and that they demonstrate that energy is never destroyed, an important part of **CCC #5 - Energy and Matter.**

Access for Multilingual Learners

Rather than assigning a list of vocabulary words—a technique that rarely works for learning new vocabulary—this activity allows language learners to learn vocabulary from context, which may be particularly helpful for **transitioning** language learners, who already have some mastery of language.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following **key points**:

- The galaxy light spectra data appears to have the absorption signature of hydrogen and helium, but shifted to the red side of the spectrum
- The galaxy light spectra data shows that the further a galaxy is the more the absorption signature of hydrogen and helium is shifted to the red side of the spectrum
- In the simulations waves (sound or light) are perceived as longer by an observer when the waves are moving away, and perceived as shorter by an observer when the waves are moving toward the observer.
- Longer wavelengths are seen in the absorption lines of galaxies appearing further on the red side of the spectra as we look at galaxies further and further away, this means these galaxies must be moving away from us - the universe is expanding.
- The redshift observed in the spectra of galaxies is explained by the expansion of the universe.

Note: The class has not yet explained the origin of the universe, but that is coming up!

7. Display the categories of ideas about how all the matter in the universe came into existence that students generated during the Engage phase. Ask students if there are ideas on the class list that can be:
    a. eliminated based on our investigation of galaxy spectra data;
    b. changed based on our investigation of galaxy spectra data;
    c. added based on our investigation of galaxy spectra data.

8. Modify the list of student ideas about the red shift in galaxy light spectra data based on student responses.

9. Return to student questions from the start of the 5E (the Engage), in order to bring up lingering issues not yet resolved, and new issues that have come up, such as:
    - Where did all the matter in the universe come from?
    - Has the universe always been the same? What was it like in the past?
    - Is it probable that there is life elsewhere in the universe?

10. Point out that so far the class has only made an evidence-based claim that the universe has been expanding. Let students know that they will have the opportunity to analyze additional evidence about the origin of the universe generated by models.

Summary

1. Students individually complete *Summary Task*. This can be completed as an exit ticket or for homework.
2. The results of this task can be used to make determinations about which students need more time to circle back to the ideas in this text in the coming parts of the 5E lesson.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas:
1) understanding how they are **using the three dimensions to make sense of a phenomenon**; 2) ideas about how they and their peers are **building knowledge together**; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

Exploring additional evidence for the Big Bang theory and constructing an explanation for the origin of the universe

Students hypothesize and read a text about what the **temperature and pressure** of the **early universe** must have been like and learn about the **law of conservation of mass and energy**. Students use what they learn about the early universe and **conservation of mass and energy** to articulate why **cosmic background microwave radiation** and **Hydrogen and Helium ratios** in the universe **serve as additional evidence for their final explanatory models**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ How did it all start?	None	❏ Balloons ❏ Permanent markers ❏ Murmur of a Bang ❏ Origins of the Universe 101

If the universe is expanding, what did it look like in the past?

1. Pose the guiding question:

If the universe is expanding, what can we conclude about what it was like over 13 billion years ago?

2. Have students carry out the balloon modeling activity in Part 1 of *Could there be other Earth-like planets?* to make inferences about what the universe must have been like in the past. Use probing questions to support students in arriving at the conclusion that if the universe is expanding, then it must have been much smaller and dense early in its history.

Look & Listen For

While students are engaged in modeling activity circulate and listen for these ideas:

- If the universe is expanding, then it must have been smaller in the past and the galaxies must have been closer together
- The further you go back in time, the smaller the universe was, meaning the galaxies were closer together
- At the beginning of time, the universe must have been clumped together

How can we test our claim of a small, dense, and hot early universe?

1. Direct students to begin Part 2 of their handout to extrapolate what the early universe would have looked like and how it might have changed as it expanded.
2. After students have done questions 1-3, engage the class in a discussion of their conclusions. Once the class has come to consensus around the idea that the universe was likely very hot, bright, and dense, let students know that these are the same claims that many scientists made based on galaxy light spectra data, and they called this theory, the Big Bang theory.
3. Have students turn back to finish reading the text in Part 2 of their handouts.
4. For added context, show students the video: Origins of the Universe 101 , up to 1:10
5. Share with students that scientists kept testing the Big Bang theory by thinking about the conditions of a compact early universe and what evidence of those conditions they should be able to find today. Let them know that they will explore this further in the next activity, and that it will be important to consider what they have learned about the behavior of energy within a system as they continue to investigate.
6. As a class, read the beginning of Part 3, in which students are introduced to the way scientists use computational models to predict what the universe used to look like and how that would impact the observed universe today.
7. Tell students that, in order to understand how conditions of the universe changed over time, we need to understand some fundamental properties of the universe relating to the light that we already learned about.
8. Ask students to think about the light and sound waves from the Light Spectra of Other Galaxies Investigation. Was the energy in those models ever destroyed?
9. Ask students to think about energy sources they have learned about before. Prompt them to think about where the energy comes from in their cell phones or other battery-powered devices; and to think about the energy emitted from stars in Unit 1. Ask them to decide if they think new energy can be created.
10. Ask students to recall what they learned during unit 1 in the Star Life Cycle 5E about conservation of matter. When students have surfaced the idea that matter is not created or destroyed, build upon that by sharing with students that scientists have also proven over and over that this is also true about energy within all systems.

Look & Listen For

Pause the discussion and ask for clarification, particularly of the following **key points**:

- Energy cannot be created or destroyed, but it can move and change
- Matter cannot be created or destroyed, but it can move and change

11. Tell students that they are now going to do what scientists do and test their claim about where all the stars and planets in the universe came from by making predictions about what the universe should look

like if the big bang theory is correct and then comparing their predictions to observed data from the universe today. Have students work in pairs to respond to steps 1-6 in Part 3 of their handouts in order to form predictions. Students will use a balloon to support them in visualizing the changes that will occur as the balloon universe expands. For New York State teachers, the spectrum diagram in this section comes from page 3 of the ESSRT.

12. When students are finished with Part 3, have pairs turn to Part 4, comparing their predictions to observations of the Universe today.
13. Confer with students as they respond to the prompts and carry out the modeling activity.
14. Have students independently link evidence we find today to the claim of the Big Bang by completing the *Bringing all the evidence together* section of the student handout.

Class Consensus Discussion

1. Orient the class to the purpose and the format of the group learning routine **Class Consensus Discussion**. You may say something like this:

"We have a lot of different ideas circulating in the room right now, and they are in the form of different scientific explanations. It is really important for us to get to some agreement on how we represent what we know about why there is a shift in the light spectra data of other galaxies when compared to the spectra of stars in our galaxy, so that we have a shared understanding to build upon as we move ahead. In order to do this we are going to do something called a **Class Consensus Discussion**. First I will select a few different groups to share their ideas. Then, we will let each group share their claim and discuss what we can agree to as a class."

You may decide to walk students through the entire poster, or take them through the steps as you facilitate it.

Class Consensus Discussion Steps

- We select a few different groups' ideas.
- The first group shares out their work.
- One person repeats or reiterates what the first group shared.
- Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

- Everyone confers in table groups.
- Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three groups' claims to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of how the evidence available to us supports the Big Bang Hypothesis. The decision about which claims to share with the class should be based on both the ideas circulating in the classroom *and* the goals of this part of the 5E sequence. Look ahead to the "Take Time for these Key Points" below to help you determine which groups you want to share out, so that those key points are surfaced.

Classroom Supports

Post the steps to the Class Consensus Discussion in the room, as a reference you can return to in future lessons.

Integrating Three Dimensions

The prompt about the law of conservation of energy and matter in the Class Consensus Discussion is in support of students' consideration of the foregrounded CCC. Here students have an opportunity to think about how knowing that all energy and matter in the universe is conserved is useful when making sense of a phenomena, including the formation of the universe. This relates to the idea that **energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems**, an important element of **CCC #5 Energy and Matter** at the high school level.

3. Ask the first group to share their claim. You can do this by:
    - Projecting using a document camera; OR
    - Copying the claims to be shared and passing them out to the class; OR
    - Taking a picture of each model and projecting them as slides.

4. Proceed through the steps in the Consensus Discussion Steps.

5. Before table groups confer, prompt them to consider the role of the law of conservation of energy and matter in figuring out which claim is best supported. Some prompts you might provide are:
    a. How was considering the law of conservation of energy and matter helpful in connecting the different pieces of evidence to the claims?

6. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk; use the guidelines below to ensure the class focuses on ideas that will drive the lesson and unit forward.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following **key points**:
- The law of conservation of matter and energy tells us that the hydrogen, helium and energy that existed soon after the universe began should still be around today, but perhaps in a different form
- The balloon model tells us that nothing would happen to the hydrogen:helium ratio as a result of universe expansion
- The balloon model tells us that the visible light energy waves would elongate, and therefore be a longer wavelength, as a result of universe expansion

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7. Display the categories of ideas about how the Sun works that students generated during the Engage phase. Ask students if there are ideas on the class list that can be:
    a. eliminated based on our investigation of the origin of the universe;
    b. changed based on our investigation of the origin of the universe;
    c. added based on our investigation of the origin of the universe.

8. Return to student questions from the start of the 5E (the Engage), in order to bring up lingering issues not yet resolved, and new issues that have come up, such as:
    - Is it probable that there is life elsewhere in the universe?

9. Use this question to transition to the Evaluate phase where students will use models to make predictions about whether life exists elsewhere in the universe.

Evaluate

Is it probable that there is life elsewhere in the universe?

Students **use models** for **how the origin of the universe led to the formation of solar systems** to **make predictions** about whether life exists on other planets.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs ❏ Individual ❏ Small groups of 3-4 students	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Could there be other Earth-like planets? ❏ Revisiting the Performance Task: Origin of the Universe 5E	None	❏ Chart paper ❏ Sticky notes ❏ Markers ❏ How Many Stars?

Revisit the Performance Task

1. Remind students that we are hoping to come up with an answer to the question about if there is likely life on other planets, and that part of that answer would come from knowledge of if there are other planets like ours in the universe.

2. Remind students of the video How Many Stars?

3. Provide students with the handout *Could there be other Earth-like planets?*, and have students work in pairs to answer the prompts

4. Then, have students independently respond to the prompts in the handout *Revisiting the Performance Task: Origin of the Universe 5E*. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop their models. Prompt students to return to the class wide scientific argument characteristics, posted in the room.
Suggested conferring questions:

- What evidence did you generate in this 5E sequence?
- Where did the evidence come from?
- How well does that evidence support the claim?
- What ideas or contradictory evidence weaken the claim?

5. Ask students to work in table groups to collaboratively develop a group model. These should go onto new pieces of chart paper.

6. Facilitate student critique of one anothers' models through the Group Learning Routine **Idea Carousel**. Have students annotate other groups' models using post-its. Each post it should have a symbol and comment from each of the following categories:
   a. ✔ Write a check on sticky notes with comments about ideas represented in the model that resonate.
   b. **+** Write a plus symbol on sticky notes with comments about ideas that should be added to the model.
   c. **?** Write a question mark on sticky notes with comments about ideas that you don't think are relevant to the model.
   d. **Δ** Write a delta symbol on sticky notes with comments about suggestions for how to clarify an idea or represent it more clearly.

Look & Listen For

While students are engaged in the Idea Carousel, listen for the following ideas. Where needed, discuss with groups what is coming up in their models, to ensure these points emerge in the classroom.

- The universe started as all one incredibly hot and small mass, then suddenly expanded in all directions.
- The processes that formed our galaxy and the solar systems within it, were taking place everywhere in the universe, so all those galaxies and solar systems must have many characteristics that are similar to the characteristics of our galaxy and solar system.
- The universe is bigger than we can even imagine.
- The number of chances there are for life to appear / exist across our universe are extremely high which makes it seem probable that life exists elsewhere.

7. At the end of the Idea Carousel, it may be the case that some specific ideas have surfaced in some groups but not others. If that is the case, prompt those groups to share with the class. A share-out from every group, however, is not needed at this point.

8. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Revisit the Driving Question Board

1. Use the **Driving Question Board Routine** to discuss which of the class's questions have been answered.
2. Have students identify which categories or questions they have not figured out yet. Prompt students to share out these questions, and document new questions that arise based on what they have been learning.
3. Add new questions to the Driving Question Board.
4. Ask students if they think that it is likely that there are other Earth-like planets on which intelligent life could have evolved. Ask them if they think extinction events could have impacted intelligent societies that may have existed in the past. Ask them if they think our own society could go extinct before we make contact with other societies.
5. Use these questions to transition to the next investigation about the stability of the solar system

Standards in Origin of the Universe 5E

Performance Expectations

HS-ESS1-2	**Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.** Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium). Assessment Boundary: None

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. SEP5(2) Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2) • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. SEP6(4)	ESS1.A The Universe and Its Stars • The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. ESS1.A(2) • The big bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. ESS1.A(3) • 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. ESS1.A(4)	Energy and Matter • Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. CCC5(3)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Using Mathematics and Computational Thinking		*Investigating Light Spectra from Other Galaxies*	*Summary Task*		
Constructing Explanations and Designing Solutions			*What does the light spectra of galaxies tell us?*	*How did it all start?*	*Revisiting the Performance Task: Origin of the Universe 5E*
ESS1.A The Universe and Its Stars	*How did the universe form?*	*Investigating Light Spectra from Other Galaxies*	*What does the light spectra of galaxies tell us?*	*How did it all start?*	*Revisiting the Performance Task: Origin of the Universe 5E*
Energy and Matter		*Investigating Light Spectra from Other Galaxies*	*What does the light spectra of galaxies tell us?* *Summary Task*	*How did it all start?*	*Revisiting the Performance Task: Origin of the Universe 5E*

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		MP1 MP2 MP4	MP2	MP2	MP1 MP2
ELA/Literacy		RST.9-10.3 RST.9-10.5 SL.9-10.1 SL.9-10.4	RST.9-10.1 WHST.9-10.2 SL.9-10.1 SL.9-10.4	RST.9-10.1 RST.9-10.2 WHST.9-10.8	RST.9-10.1 WHST.9-10.2 WHST.9-10.4 WHST.9-10.10 SL.9-10.4

Asteroid Orbits 5E

Will a major asteroid ever hit the Earth again? How do we know, and what can humans do to survive?

Performance Expectations
HS-ESS1-4

Investigative Phenomenon
Apophis, a 300 meter wide asteroid, orbits the Sun in a path that crosses the Earth's orbit. Based on its current trajectory and speed, it is expected to cross Earth's path on April 23, 2029 at around 4:30 PM EST. It will pass so close to Earth that it will be visible without a telescope. It will be the largest asteroid to come so close in our recorded history.

Time
5-7 days

In this 5E instructional sequence, students are investigating the questions about the risk of asteroids to the Earth currently. Students answer questions surfaced during the Driving Question Board such as "How do we predict the path of an asteroid?" or "Are we currently at risk?"

ENGAGE	What are the chances of another major asteroid hitting Earth?	Students watch a video about tracking Near Earth Objects (NEO) and use Nasa's Eyes on Asteroids to observe Apophis' 2029 near Earth flyby, then **generate questions** about how we know that Apophis' **orbit** will **stay stable or if it will change**.
EXPLORE	What patterns do different objects follow as they travel through space?	Students **collect evidence** from the **movements of planets, comets and asteroids** in order to **construct an explanation** for the **stable pattern in the orbit of solar system objects** like Apophis.
EXPLAIN	How do we predict motions of asteroids and planets?	Students **use mathematical models based on evidence** from the **movements of planets, comets and asteroids** to **describe and explain** the **stable patterns in the orbits of solar system objects** like Apophis .
ELABORATE	Will Apophis hit Earth in the 2030s?	Students **use** what they know about **gravity and collisions and Newton's mathematical representation of gravity** to **explain how Apophis' path can be changed** by Earth's gravity in 2029, then develop a claim for **what solution can change the path** of an asteroid if it is predicted it will hit Earth in the future.
EVALUATE	What can humans do to defend the planet from another asteroid mass extinction?	Students **use a mathematical representation of gravity** and knowledge of **how collisions affect orbits** to **support a claim** for what solution **can change the path of an asteroid** if it is predicted it will hit Earth in the future.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

What are the chances of another major asteroid hitting Earth?

Students watch a video about tracking Near Earth Objects (NEO) and use Nasa's Eyes on Asteroids to observe Apophis' 2029 near Earth flyby, then **generate questions** about how we know that Apophis' **orbit** will **stay stable or if it will change**.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Asteroids in the Solar System	None	❏ Apophis ❏ Meet the NASA Scientist Who Tracks Dangerous Asteroids in Earth's Orbit

Launch and Surfacing Student Ideas

1. Remind students that, during the Driving Question Board launch and at the end of the last 5E, one category of questions that emerged was related to where asteroids come from, how many asteroids like the one that killed the dinosaurs still exist in the solar system, and whether another large asteroid can hit the Earth in the future. Prompt students to consider that we also have begun discussing the chances of intelligent life existing elsewhere in the universe, and the odds of it being wiped out if it did exist.

2. Distribute the handout, *Asteroids in the Solar System* and use students' questions to transition to the video, Meet the NASA Scientist Who Tracks Dangerous Asteroids in Earth's Orbit . Tell students to watch the video and note ideas that help them answer their questions as well as new questions in part 1 of their handout.

Look & Listen For

- There is a very large reservoir of asteroids that is between Mars' and Jupiter's orbits – probably has about a billion objects.
- Gravity from Jupiter and Saturn nudge them closer to Earth.
- There are millions of objects that are at least 50 meters and can destroy cities.
- A small 17 meter asteroid disintegrated in Earth's atmosphere. It still injured over a thousand people.
- NASA scientists are tracking these objects very closely and if they detect one that they think will hit Earth, we will probably have about 3 years to figure out what to do. One idea is crashing a spacecraft into it so it is knocked off course.
- Are there any asteroids or objects that NASA is especially concerned about?

3. Tell students that there is one particular asteroid that has NASA's attention right now. Show the video, Apophis . Ask students to note observations, thoughts, and questions based on the video in the See-Think-Wonder found in part 2 of their handout.

4. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections.

Look & Listen For

Possible student ideas and questions that can be used to transition to the next phase(s):

- I think it can cause a lot of damage to life on Earth.
- It seems like NASA scientists know exactly how far Apophis will come from Earth and its overall trajectory.
- I know we have models that help us predict how far a planet is from its star on average and we can calculate the shapes of orbits, but what else do we need to know?
- How do they know the path Apophis will follow is correct or that it will continue to be the same?

5. Students may not surface all the ideas above and that's ok at this point. Let them know that they will have a chance to test their ideas and change or refine them as they carry out an investigation.

Explore

What patterns do different objects follow as they travel through space?

Students **collect evidence** from the **movements of planets, comets and asteroids** in order to **construct an explanation** for the **stable pattern in the orbit of solar system objects** like Apophis.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs (Investigation) ❏ Table Groups (Investigation Summary)	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Asteroid Paths and Velocities Investigation	None	❏ Kepler's Second Law ❏ Gravity ❏ Gravity and Orbits

Launch

1. Tell students that they will now have the opportunity to investigate their questions regarding how we are able to predict the path of asteroids and other objects. Ask students how they have learned about this in the past when they learned about Kepler's 1st and 3rd laws and ask a few students to share out.

Look & Listen For

- When we learned about Kepler's 1st and 2nd laws we did that by looking for patterns in the movement of a lot of solar system objects.
- We used tech tools to analyze the relationships.
- We generated a mathematical model to describe those relationships.

2. Let students know that they will have the opportunity to apply some similar approaches in order to refine their understanding of how we can predict the orbits of asteroids and other objects in the solar system.

Investigation: Asteroid Paths & Velocities

1. Provide each student with the *Asteroid Paths and Velocities Investigation* handout.
2. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

Confer with students during the investigation. Suggested during-lab conferring questions:

- What do you notice about the amount of area between the planet and the Sun for each sweep?
- What is the relationship between the distance from the star and the length of the orbit covered during a sweep?
- How might this relationship between the distance from the star and the length of the orbit covered during each sweep account for the equal area during each no matter where the object is?
- What do you notice about how much time it takes for the planet to complete each sweep? Is the amount of time for each sweep affected by the length of the orbit during a sweep?
- What do you notice about the relationship between the distance from the star and the velocity of the object?
- How does the velocity of the object at different times relate to its proximity to the sun? Does this help explain the patterns you see in the amount of time it takes to complete a sweep?

Integrating Three Dimensions

In this phase, students are determining the relationship between the distance a planet is from its star and its orbit, investigating how the change in one variable affects the other, which is a key part of **CCC#3 - Scale, Proportion, and Quantity** at the high school level.

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the See-Think-Wonder section, then use these completed pages to discuss the findings from the investigation.

3. Ask groups to come up with one important idea to share with the whole class, from their Summary notes.

4. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from groups' Summary sections.

Routine

The **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. It allows students to learn from each other and for the teacher to assess whether the class is ready to move to the next phase of instruction. Refer to the Earth & Space Science Course Guide for support with this routine.

Look & Listen For

These student observations and ideas are critical to students' success during the Explain phase:

- Despite the fact that each sweep covers a different length of orbit, the area between the planet and the object is the same and is covered in the same amount of time.
- As the distance from the star increases, the length of the orbit covered during a sweep decreases.
- Since the length of orbit covered during a sweep decreases as the distance increases (and vice versa), that would explain why the area is always the same.
- It always takes the same amount of time for a sweep to be completed, despite the fact that the length of the orbit covered during sweeps varies.
- The velocity of the object is faster when it's closer to the star and slower when it is further.
- I think the difference in velocity explains why the object is able to cover a different lengths of the orbit in the same amount of time.

Access for Multilingual Learners

Using **Domino Discover** at this stage provides support for multilingual learners who are **emerging** and **transitioning**. Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development. Refer to the Earth & Space Science Course Guide for more information on this routine.

5. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.

Explain

How do we predict motions of asteroids and planets?

Students **use mathematical models based on evidence** from the **movements of planets, comets and asteroids** to **describe and explain** the **stable patterns in the orbits of solar system objects** like Apophis .

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Mathematical Modeling of Orbital Stability & Change ❏ Summary Task	None	

Launch

1. Remind students that during the Explore phase, they began analyzing evidence from solar system data to better understand how we know that the trajectory of an asteroid is stable. Tell students that they will now use mathematical models for the ideas they surfaced in the Explore phase to describe and explain stability in patterns of asteroid orbits.

2. Ask students to recall from their previous learning, how they have used equations to describe orbital relationships and make predictions.

Look & Listen For

- We can derive it with a spreadsheet or see if an equation that describes the relationship already exists.
- We should make sure we understand the relationship illustrated by the equation and can describe it to others.
- We can plug known numbers into the equation in order to make predictions about unknown variables.

Integrating Three Dimensions

In this unit students are continuing to develop their facility with **SEP#5 Using Mathematics or Computational Thinking,** specifically using a mathematical or computational representations of phenomena to describe and / or support claims or explanations, an important element of **SEP#5** at the high school level.

Using Mathematical Models to Explain Stability of Orbital Trajectory

1. Provide students with the handout, *Mathematical Modeling of Orbital Stability & Change*. Ask students to work in pairs or small table groups as they use mathematical models to describe and explain the orbit of objects in the solar system.

2. Confer with students as they work on their explanations. During unit 1 students learned about Kepler's 1st and 3rd laws. Prompt students to consider what Kepler's 1st and 3rd laws allow us to predict about orbits and include those ideas in their models.

Conferring Prompts

- What would happen to the value of the variable if that variable goes up? Down?
- Have you tried plugging numbers into check that the way you are describing the relationship holds true?
- How does Newton's Law of Gravitational Force relate to Kepler's 2nd Law?

Integrating Three Dimensions

Use the Conferring Prompts to support students' further development of the idea that mathematical or computational representations of phenomena can be used to describe and / or support claims or explanations, an important element of **SEP#5 Using Mathematical or Computational Thinking** at the high school level.

Class Consensus Discussion

1. Orient the class to the purpose and the format of a class consensus discussion. You may say something like this:
   - "We are going to use a **class consensus discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to some decisions about what explains stability and change in patterns of asteroid orbits."

Class Consensus Discussion Steps

1. We select a few different groups' ideas.
2. The first group shares out their work.
3. One person repeats or reiterates what the first group shared.
4. Class members ask clarifying questions about the work.

Repeat steps 2-4 for each group that is sharing work.

5. Everyone confers in table groups.
6. Engage in whole-class discussion about the ideas that were shared, in order to come to agreement.

2. Select two or three student models from part 2 to share with the class. At this point, do not select them randomly. The point of this discussion is to elevate ideas that move the class towards greater understanding of what explains stability and change in patterns of asteroid orbits. The decision about

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

which explanations to share with the class should be based on both the ideas circulating in the classroom and the goals of this part of the 5E sequence.

3. Ask the first student or group to share their explanation. You can do this by:
   - Projecting using a document camera; OR
   - Copying the written explanation to be shared and passing them out to the class; OR
   - Taking a picture of each explanation and projecting them as slides.

4. Proceed through the steps in the Consensus Discussion Steps.

5. During the whole-class discussion, there will be opportunities to identify important terms and concepts that emerge in the discussion. Sometimes, important points get buried in student talk.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:

- We can predict when the asteroid will pass by Earth using Kepler's 3rd law.
- We can predict how fast it will be moving by using Kepler's 2nd law.
- We can predict the trajectory or the shape using Kepler's 1st law.
- The mechanism for what we are claiming with Kepler's 2nd law (relationship between distance between star and celestial object velocity) is related to gravity.
- All these motions have occurred in a predictable stable pattern, so we can feel pretty good about our predictions.

6. Return to student questions that bring up lingering issues not yet resolved, such as:
   - How can gravity from the Earth affect Apophis' path?
   - What do we do if we discover that Apophis or another asteroid like it is going to hit the Earth? How can we alter its course?

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to support students' further development of **CCC#7 Stability & Change** by elevating and probing for ideas related to the concept that **much of science deals with constructing explanations of how things change and how they remain stable** in the context of this investigation about predicting planet trajectories / orbits.

Summary

1. Students individually complete the *Summary Task*. This can be completed as an exit ticket or for homework.

2. The results of this task can be used to make determinations about which students need more time to engage in sense-making about what explains stability and change in patterns of asteroid orbits.

Implementation Tip

This summary is really important! It's an opportunity to check in on each student's thinking at this point in the unit, in a few different areas: 1) **understanding how they are using the three dimensions to make sense of a phenomenon** 2) ideas about how they and their peers are building knowledge together; 3) how they think the class consensus discussion went. It's important to get all of this from individual students, so you know these things on a student-by-student basis.

Elaborate

Will Apophis hit Earth in the 2030s?

Students **use** what they know about **gravity and collisions and Newton's mathematical representation of gravity** to **explain how Apophis' path can be changed** by Earth's gravity in 2029, then develop a claim for **what solution can change the path** of an asteroid if it is predicted it will hit Earth in the future.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Read-Generate-Sort-Solve	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Will Apophis hit Earth in the 2030s?	None	

Using Mathematical Models to Predict Change in Orbital Trajectory

1. Remind students about their questions regarding how gravity from the Earth can affect Apophis' path and what we do if we discover that Apophis or another asteroid like it is going to hit the Earth.
2. Provide students with the handout, *Will Apophis hit Earth in the 2030s?*.
3. Tell students that they will now have an opportunity to use evidence and scientific reasoning to develop an explanatory model for how gravity from the Earth can affect Apophis' path.
4. Facilitate the group learning routine **Read-Generate-Sort-Solve**, as a way for students to synthesize and extend their thinking.

Routine

The **Read-Generate-Sort-Solve** routine promotes collaborative engagement in problem-solving and supports students in articulating their thinking and making it transparent, before considering solutions. Please read the Earth & Space Science Course Guide for detailed steps of this routine.

Look & Listen For

While students are engaged in the Read-Generate-Sort-Solve, listen for the following ideas. Where needed, discuss with groups what is coming up in their models, to ensure these points emerge in the classroom.

- Scientists have investigated orbits of objects in the solar system extensively and have been able to find empirical evidence for stable patterns in the way they orbit the Sun.
- They have used the concept of gravity and mathematical representations of gravity to explain these patterns.
- Kepler developed mathematical models that describe the orbital motion of objects and we can use them to make predictions about their paths, including the paths of near Earth objects like Apophis.
- Understanding what determines the stable paths of asteroids and how gravity and collisions can change those orbits allows us to make even better predictions of when an asteroid is likely to hit Earth.

Access for All Learners

Read-Generate-Sort-Solve is an important routine because it builds in individual think time and opportunities for all students to contribute to the group answer. Students who need additional processing time, or a chance to adjust their thinking after hearing from peers, get that opportunity. This additional time for language input is especially helpful for **emerging language learners**.

Evaluate

What can humans do to defend the planet from another asteroid mass extinction?

Students **use a mathematical representation of gravity** and knowledge of **how collisions affect orbits** to **support a claim** for what solution **can change the path of an asteroid** if it is predicted it will hit Earth in the future.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Independent	❏ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Deflecting Asteroids ❏ Revisiting the Performance Task: Asteroid Orbits 5E	None	❏ Rusty Schweickart: What is the Gravity Tractor Deflection Method for Deflecting NEAs

Revisit the Performance Task

1. Provide students with the handout *Deflecting Asteroids*.
2. Introduce the technology of gravity tractors by reading the text in the handout, observing the image, and showing the video Rusty Schweickart: What is the Gravity Tractor Deflection Method for Deflecting NEAs .
3. Have students independently respond to the prompts in their performance task research organizer for this Asteroid Orbits 5E.
4. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop their arguments. Prompt students to return to the class wide scientific argument characteristics, posted in the room.
Suggested conferring questions:

- What evidence did you generate in this 5E sequence?
- Where did the evidence come from?
- How well does that evidence support the claim?
- What ideas or contradictory evidence weaken the claim?

5. Ask students to work in table groups to collaboratively develop a group model. These should go onto new pieces of chart paper.

6. Facilitate student critique of one anothers' models through the Group Learning Routine **Idea Carousel**. Have students annotate other groups' models using post-its. Each post it should have a symbol and comment from each of the following categories:
    a. ✔ Write a check on sticky notes with comments about ideas represented in the model that resonate.
    b. ➕ Write a plus symbol on sticky notes with comments about ideas that should be added to the model.
    c. **?** Write a question mark on sticky notes with comments about ideas that you don't think are relevant to the model.
    d. **Δ** Write a delta symbol on post its with comments about suggestions for how to clarify an idea or represent it more clearly.

Look & Listen For

While students are engaged in the Idea Carousel, listen for the following ideas. Where needed, discuss with groups what is coming up in their models, to ensure these points emerge in the classroom.

- Understanding what determines the stable paths of asteroids and how gravity and collisions can change those orbits allows us to make even better predictions of when an asteroid is likely to hit Earth and formulate plans to change its path and save life on the planet.
- We send a large spaceship and have it use its gravitational force to change the path of the asteroid. The spaceship would have to have enough mass to have enough gravity to accomplish this goal.
- We send a large spaceship and have it collide with the asteroid to change the path.

7. At the end of the Idea Carousel, it may be the case that some specific ideas have surfaced in some groups but not others. If that is the case, prompt those groups to share with the class. A share-out from every group, however, is not needed at this point.

8. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Standards in Asteroid Orbits 5E

Performance Expectations

HS-ESS1-4 **Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.**
Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.
Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. SEP5(2) Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2)	ESS1.B Earth and the Solar System • Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the Sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. ESS1.B(1)	Scale, Proportion, and Quantity • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). CCC3(5)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Using Mathematics and Computational Thinking		*Asteroid Paths and Velocities Investigation*	*Mathematical Modeling of Orbital Stability & Change* *Summary Task*		
Constructing Explanations and Designing Solutions			*Mathematical Modeling of Orbital Stability & Change*	*Will Apophis hit Earth in the 2030s?*	*Revisiting the Performance Task: Asteroid Orbits 5E*
ESS1.B Earth and the Solar System	*Asteroids in the Solar System*	*Asteroid Paths and Velocities Investigation*	*Mathematical Modeling of Orbital Stability & Change* *Summary Task*	*Will Apophis hit Earth in the 2030s?*	*Revisiting the Performance Task: Asteroid Orbits 5E*
Scale, Proportion, and Quantity		*Asteroid Paths and Velocities Investigation*	*Mathematical Modeling of Orbital Stability & Change* *Summary Task*	*Will Apophis hit Earth in the 2030s?*	*Revisiting the Performance Task: Asteroid Orbits 5E*

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		MP1 MP2 MP4	MP2 MP4	MP2 MP4	MP1 MP2 MP4
ELA/Literacy	RST.9-10.2	RST.9-10.7 SL.9-10.1	RST.9-10.7 WHST.9-10.4 SL.9-10.1 SL.9-10.4	WHST.9-10. SL.9-10.1 SL.9-10.4	RST.9-10.1 WHST.9-10.2 SL.9-10.4

Unit Closing

Does life exist somewhere outside of Earth? What about intelligent life?	**Performance Expectations** HS-ESS1-6, HS-ESS2-7	**Anchor Phenomenon** 4.5 billion years passed and 5 mass extinctions occurred before intelligent life evolved on Earth.	**Time** 1-2 days

Students combine their learning from the unit to consider what the likelihood is that the conditions required for life to have evolved on Earth also appear on other planets or celestial bodies.

ANCHOR PHENOMENON	What is the probability of intelligent life existing outside Earth?	Students generate more ideas about the possibility of life existing outside of Earth.
DRIVING QUESTION BOARD	What questions have been answered? What have we not answered yet?	Based on the investigations and learning throughout the unit, students return to the Driving Question Board to reflect on questions generated throughout the unit.
PERFORMANCE TASK	What is the probability of intelligent life existing outside Earth?	Students respond to the performance task to argue the possibility of life existing outside of Earth.
UNIT REFLECTION	How can we evaluate our learning?	Students reflect on what they learned in this unit, and in the entire Earth Science course.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

What is the probability of intelligent life existing outside Earth?

Students generate more ideas about the possibility of life existing outside of Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Generating Ideas about Anchor Phenomenon

Students return to the anchor phenomenon and consider the probability of finding life outside of Earth. They review their ideas about the history of the universe and solar system, the evolution of life on Earth, and Kepler's Laws.

Driving Question Board

What questions have been answered? What have we not answered yet?

Based on the investigations and learning throughout the unit, students return to the Driving Question Board to reflect on questions generated throughout the unit.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	❏ Driving Question Board

Revisit the Driving Question Board

Students return to the questions generated throughout the unit and reflect. What questions have been answered? Are there questions that we still need to investigate?

Note that not all of the students' questions will be answered at the end of the unit, and students may have generated entirely new questions. Depending on student interest and instructional time, prompt students to explore some of the unanswered questions independently.

Performance Task

What is the probability of intelligent life existing outside Earth?

Students respond to the performance task to argue the possibility of life existing outside of Earth.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Unit Closing Task: Construct and Defend an Argument	None	

Final Performance Task

1. Let students know that they will now be able to apply all their learning to the unit to write their final argument about whether intelligent life exists elsewhere in the universe, then have an oral argument based on evidence with their classmates.

2. Provide students with the Unit Closing Task in the *Unit Closing Task: Construct and Defend an Argument*. Discuss the Drake equation. Help students understand the connections between the factors in the Drake equation and the topics they have been studying in this unit. They should see that the first two expressions (R and f*p*) relate to the number of stars resulting from the origin of the universe, the next expression (n*e*) relates to the presence of water and the stability of the planet, the next three relate to evolution (f*l*, f*i*, and fc), and the final one (L) relates to avoiding extinction, as discussed in the asteroid orbits 5E.

3. Have students write their arguments independently, and then facilitate oral argumentation through a socratic seminar or debate.

Unit Reflection

How can we evaluate our learning?

Students reflect on what they learned in this unit, and in the entire Earth Science course.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Course Learning Reflection

1. As the final unit in the course, provide students with the opportunity to reflect on their own learning. It may be helpful to prompt students to look at their work over the course of the year (performance tasks, notebook, portfolios, etc) so that they can observe their own growth across all three dimensions, and as science-knowers.

Standards in Unit Closing

Performance Expectations

HS-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.**
Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.
Assessment Boundary: None

In NYS, the phrase "Earth's oldest minerals" has been replaced with "Earth's rocks and minerals."

HS-ESS2-7 **Construct an argument based on evidence about the simultaneous coevolution 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 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.

In NYS the clarification statement has been edited as follows: 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 could include how the outgassing of water from Earth's interior caused the development of Earth's early oceans leading to the evolution of microorganisms and stromatolites; 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.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence • Construct, use, and/or present an oral and written argument or counter- arguments based on data and evidence. SEP7(4)	ESS1.A The Universe and Its Stars • The big bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. ESS1.A(3) ESS1.C The History of Planet Earth • Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. ESS1.C(2) ESS2.C The Roles of Water in Earth's Surface Processes • 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. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit Sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. ESS2.C(1) ESS2.D Weather and Climate • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. ESS2.D(2) ESS2.E Biogeology • The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of	Stability and Change • Much of science deals with constructing explanations of how things change and how they remain stable. CCC7(1)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
	Earth’s surface and the life that exists on it. ESS2.E(1)	

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Engaging in Argument from Evidence			*Unit Closing Task: Construct and Defend an Argument*	
ESS1.A The Universe and Its Stars			*Unit Closing Task: Construct and Defend an Argument*	
ESS1.C The History of Planet Earth			*Unit Closing Task: Construct and Defend an Argument*	
ESS2.C The Roles of Water in Earth's Surface Processes			*Unit Closing Task: Construct and Defend an Argument*	
ESS2.D Weather and Climate			*Unit Closing Task: Construct and Defend an Argument*	
ESS2.E Biogeology			*Unit Closing Task: Construct and Defend an Argument*	
Stability and Change			*Unit Closing Task: Construct and Defend an Argument*	

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Mathematics			MP2 MP4	
ELA/Literacy			RST.9-10.1 WHST.9-10.1 SL.9-10.1 SL.9-10.4	