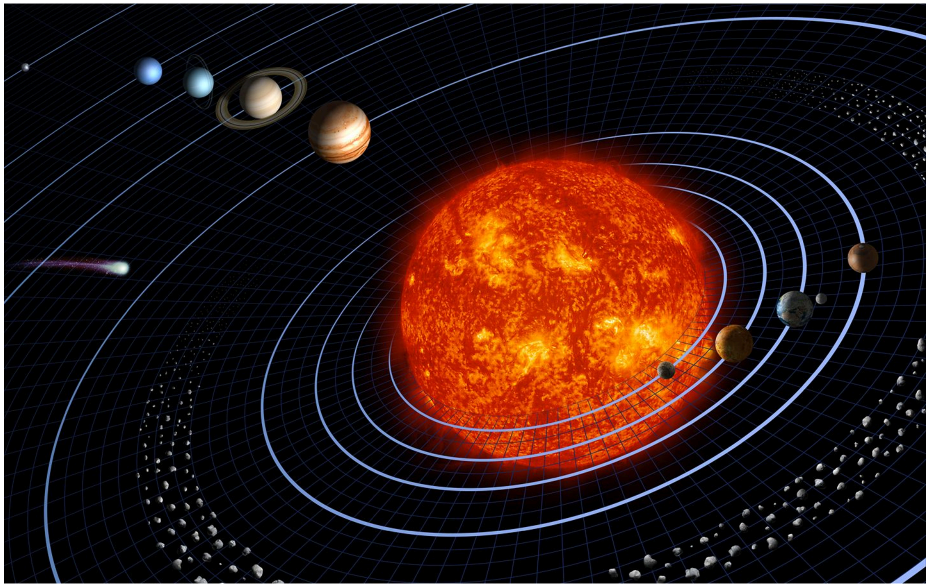
Discovering New Worlds - Teacher Materials

Unit 1	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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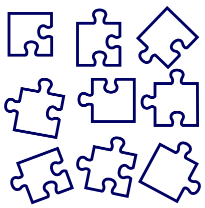
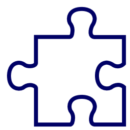
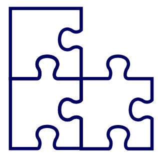
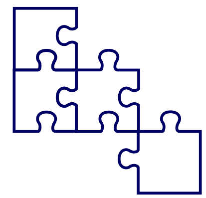
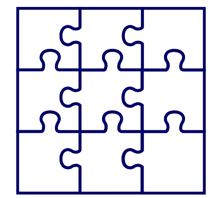
Unit 1 Discovering New Worlds
Planets and Stars

Performance Expectations
HS-ESS1-1, HS-ESS1-3, HS-ESS1-4

Time
23-29 days

What makes Earth ideal for life? Are there any other Earth-like planets out there?

For almost 12,000 years, Earth has been an ideal place for humans and other living things to evolve. But a once very livable Earth is becoming less livable due to human-caused stresses to Earth's systems. After brainstorming possible solutions, students investigate the possibility of finding another Earth-like home in our galaxy. Students develop a model to explain what makes Earth an ideal place for us to live based on patterns observed at different scales in data from simulations related to the stability of stars, planet formation, and planetary motion. They then use their models and explanations to consider other solar systems and to argue from evidence about which exoplanet is most Earth-like.

Unit Opening	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E	Unit Closing
Anchor Phenomenon	→	**5E Lessons connect learning to the performance task**	→	**Performance Task**
				
What has made Earth able to sustain life? If we are not successful in stopping the negative changes to planet Earth, is there an exoplanet that is Earth-like enough to sustain life?	*Why is the Sun so important to life on Earth? How does the Sun work? How has the Sun provided us with the right amount of energy for life to exist?*	*Does the exoplanet have a star like our Sun? What is our Sun like, compared to other stars?*	*Is the exoplanet like Earth in terms of its distance from its star? What are the factors that allow an exoplanet to maintain a stable temperature?*	*Which exoplanet is most Earth-like?*

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.

Rather than beginning our Earth and Space Science curriculum with “the scientific method,” we begin by connecting to relevant, real-world concerns about the future of life on our planet. The unit launch related to the decreasing habitability of Earth is immediately engaging to students, and the question of how we might study and explore the potential for life beyond our solar system is accessible to everyone. From day one, students are scientists, and over time they determine through a series of investigations and scientific modeling what makes Earth so livable, and whether there is an exoplanet out there that might be able to sustain life.

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 begin this year-long course. Establishing a classroom culture of learning science by doing science, rather than learning *about* science is essential, and teachers should establish this culture at the start of the school year. The embedded group learning routines and formative assessments support teachers in learning about their students, both academically and personally. Whether students had strong science programs entering high school, or if three-dimensional teaching and learning is brand new to them (or to the teacher!) this unit was purposefully designed as a way to introduce students to this way of learning and doing science in school.

Unit Coherence

In Unit 1, the overall question about searching for an exoplanet that could sustain 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 three coherent sequences of lessons within Unit 1. Each sequence is based on students’ questions and builds towards figuring out something that contributes to the overall unit-level question about what makes Earth able to sustain life. This in turn allows students to figure out which exoplanet is most similar to Earth. The phenomena, the instructional model, and the routines embedded throughout the sequences of lessons are all used in service of coherence across Unit 1.

> Introducing a challenging-yet-motivating phenomenon makes my kids want to reach the higher bar I have set. They're more engaged to dive deeper into what is going on and to push themselves to learn more. Consistently using instructional routines and tools like Rumors, Driving Question Boards, and Domino Discover have helped my students write tons of questions and have heated scientific discussions. Furthermore, knowing that the phenomenon is tough or possibly unsolvable makes students more comfortable being wrong.
>
> - Brittany Beck, HS teacher in Brooklyn

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 (three in this unit) • Presented in the Engage phase of each 5E

Anchor Phenomenon

To support coherence, students are prompted to figure 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. It is important to notice that the phenomenon question anchoring Unit 1, Out of all the planets in the Solar System, what makes Earth able to sustain life? is different from the more generalized and abstracted science question for the unit, How do stars affect the planets that orbit them? This difference is part of what helps make the unit more student-centered, rather than teacher-centered.

Investigative Phenomena

Based on the Unit 1 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		Performance Expectations	Anchor Phenomenon	Time
	What has made Earth able to sustain life? If we are not successful in stopping the negative changes to planet Earth, is there an exoplanet that is Earth-like enough to sustain life?	HS-ESS1-1, HS-ESS1-3, HS-ESS1-4	Out of all of the planets in the solar system, only Earth has life! Earth didn't have life for a long time, and now it does	2 days

Student Questions	What Students Do	Student Ideas
These questions motivate the unit storyline: • Does the exoplanet have a Sun like ours? • Where did all the planets and stars come from? • What are stars made of? • What's the temperature on the planet like? Is it hot or cold? • Does the planet have liquid water? • Can the planet sustain life? • Does the planet sustain life already? • Do the planets have resources we need? • What is gravity like on the planet? • Does the planet have oxygen and an atmosphere? • How long would it take to get to the planet? • Would it be dangerous or different to go beyond our solar system?	Students watch a video about the diversity and evolution of life on our planet and consider the scale of time for this all to occur. They develop initial models to represent what makes Earth livable. Then students interpret three data visualizations about global warming and species extinction. After landing on the possible solution of looking for an Earth-like exoplanet to live on given that Earth is becoming less habitable, they brainstorm initial questions that would help them investigate which exoplanet(s) are potential candidates.	*These ideas are revisited throughout the unit storyline:* Evidence shows that it took several hundred million years after the appearance of liquid water for life to exist and evolve on Earth. Global warming is having a negative impact on us (severe weather, flooding, public health). For example, in NYC, we could be under water in the future. Species are rapidly going extinct. Possible solutions to address the problem of Earth becoming less habitable for humans might include fixing global warming, species conservation (bring back extinct species via DNA), or going to live on a floating ship in space. One other possible solution to the problem of Earth no longer being habitable is to search for a new home on an Earth-like planet. We need to determine what to look for in data in order to find an Earth-like planet - NASA has data we can use on thousands of stars and planets outside our solar system.

During the Driving Question Board routine, student questions related to the Sun will emerge, based on their initial models of what makes Earth habitable. Once a category related to these questions has been articulated (e.g., questions related to "Does the exoplanet have a star like our Sun?"), let students know that over the next few class periods, they will begin investigating this question to figure out what is so special about our Sun and how it gives us the right amount of energy for life to exist.

How the Sun Works 5E

Why is the Sun so important to life on Earth? How does the Sun work? How has the Sun provided us with the right amount of energy for life to exist?

Performance Expectations
HS-ESS1-1

Investigative Phenomenon
Energy released by the Sun in one second is more energy than the entire world uses in a whole day .

Time
6 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • How does the Sun keep generating energy? • Where do the Sun's light and heat come from? • What is the Sun made of? • Is the Sun burning? • How hot is the Sun? • Are there explosions inside the Sun?	Connecting to their initial explanatory model of what makes Earth habitable, students articulate the need to better understand how the Sun works. Using a systems lens, they figure out what the parts of the system are before figuring out how the parts work together for the system to function. Students figure out the parts of the system by using data from a spectroscopy telescope, since elements have signature spectra. They determine that the Sun is made of H and He. This leads them to want to figure out the mechanism for generating heat and light. In other words, What is happening inside the Sun with the H and He to produce the energy that is received by us on Earth? Students consider two possible claims: either there is a chemical reaction, or nuclear fusion is taking place. By analyzing the data, students use evidence to argue about which process is occurring inside the Sun. Given the scale, they reason that it can only be nuclear fusion. Students go back to their original models for what makes Earth habitable and revise them in light of what they have figured out, adding a representation of nuclear fusion of hydrogen to create helium, and a representation of the Sun's energy reaching Earth as radiation.	*Students figure out these ideas in this 5E sequence.* • Light from the Sun produces a spectrum, which contains a signature. • Evidence indicates that stars are composed almost entirely of hydrogen and helium. • The Sun has produced a tremendous amount of energy for 5 billion years. This can only be explained by nuclear fusion being the source of its energy. • The energy produced by the Sun reaches Earth in the form of electromagnetic waves which cause Earth to heat up.

After students revise their models for how the Sun is able to support life on Earth, they are aware that there isn't enough information yet to narrow down our list of stars and exoplanets, and students revisit the DQB. To build on the previous question category related to stars (e.g.: "Does the exoplanet have a star like our Sun?"), students express a need to investigate stars further to figure out which exoplanet's star is most like our Sun (e.g.: "What do we need to know about other stars?").

Star Life Cycles 5E	Does the exoplanet have a star like our Sun? What is our Sun like, compared to other stars?	**Performance Expectations** HS-ESS1-1, HS-ESS1-3	**Investigative Phenomenon** Historical records from all over the world describe the explosion of a star in 1054.	**Time** 7 days

Student Questions	What Students Do	Student Ideas
• Can a star die? • Do stars last forever? • Are some stars older than others? How does our Sun compare? • Do all stars explode? What causes a supernova? • What is a black hole? • How big are stars? Are they all the same size? • How big is our Sun compared to other stars? • Why are some stars brighter than others? • How hot is our Sun compared to other stars?	Students read about and watch a visualization of Supernova 1054 to generate further questions about stars, what happens to them, and whether or not they change. Students use a computational model of star life cycles to look for evidence of patterns in the relationship between star mass and stability and change in stars, so that they can identify stars with the longest and most stable lifespans. Students then create and analyze a Hertzsprung-Russell diagram to look for evidence of patterns in the relationships between observable star properties and lifespan. Using their understanding of nucleosynthesis and gravity in stars, students explain the observed patterns of stability and change in star life cycles. To further investigate the impact of mass on what happens to stars, students collect data from a computational model of nucleosynthesis in stars and identify patterns they can use to explain why star stability varies according to mass, and why higher mass stars are able to produce heavier elements. After these investigations, students use evidence about how and why our stars change over time to argue about which star in the performance task data set is most likely to support an Earth-like planet.	• Our Sun is a mid-sized, Main Sequence star, with a temperature of 5778 K, in the middle of its life span. • Because main sequence stars are in a state of relative equilibrium, where gravity pulling inward is balanced by hydrogen fusion force pushing outward, the Sun has maintained a stable temperature throughout its life so far. • Stars produce elements through the process of nuclear fusion. The most massive stars explode as supernovas, producing the heaviest elements in our universe. • There are certain types of stars that are more likely to support an Earth-like planet. Stars that are most like our Sun would likely support an Earth-like planet (main sequence, mid-sized, and a stable temperature).

After students have narrowed down their list of possible stars that could support exoplanets that might be Earth-like, they revisit the Driving Question Board category related to questions about the temperature and motion of the exoplanet (Does it have an orbit similar to Earth’s around the Sun? Does it have a similar temperature range to Earth?). This leads students to investigate the orbits of the different exoplanets in our data set.

Planets and Orbits 5E

Is the exoplanet like Earth in terms of its distance from its star? What are the factors that allow an exoplanet to maintain a stable temperature?

Performance Expectations
HS-ESS1-4

Investigative Phenomenon
Comet Borrelly has water that is frozen most of the time, but every several years it shoots out a jet of vaporized water and dust.

Time
7-9 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • Do the planets have resources we need? • What is gravity like on the planet? • Will the exoplanet crash into anything in its orbit? • Does the planet have oxygen and an atmosphere? • How far away is the Sun from Earth? • What's the temperature on the planet like? Is it hot or cold? • Can the planet sustain life? • Does the planet sustain life already?	In this 5E instructional sequence, students investigate the questions surfaced during the Driving Question Board launch - Does the planet have the right temperature to sustain life? This leads to questions about the distance between planets and the stars they orbit. Students investigate the orbits of planets and objects in our solar system and develop a model for why Earth is able to maintain a temperature range that allows the liquid water to exist throughout each orbit around our Sun. They use these models and orbit data from planets in the performance task data set to argue from evidence about which planet maintains a temperature that allows for the existence of liquid water throughout a revolution around its star.	*Students figure out these ideas in this 5E sequence.* • Gravity keeps celestial objects in orbit around a star. • There is a relationship between an object's proximity to its star and the time it takes for that object to complete one full orbit around the star. • Orbits can range from nearly circular to very elliptical (eccentric). Earth's orbit is very circular, which leads to relative stability in temperature. • Highly elliptical orbits can cause major temperature shifts on a planet. We should search for exoplanets with orbits that are relatively circular, as they are more likely to be able to sustain life.

Unit Closing

Which exoplanet is most Earth-like?

Performance Expectations
HS-ESS1-1, HS-ESS1-3, HS-ESS1-4

Anchor Phenomenon
Out of all of the planets in the solar system, only Earth has life! Earth didn't have life for a long time, and now it does

Time
1-5 days

Student Questions	What Students Do	Student Ideas
These questions are addressed in the performance task. Which exoplanet is the most likely to be habitable?	Using their models and evidence about stars, along with the evidence about planetary motion around stars, students write the final version of their arguments about which exoplanet is most likely to be able to support life.	*These ideas were developed throughout the unit storyline.* • The exoplanets from the list that have the potential to sustain life are terrestrial ones that have a relatively circular orbit around a stable main sequence star approximately the size of our Sun or smaller, which would allow for liquid water to exist. • We would have to travel extremely long distances to reach Earth-like planets that we have found so far. Current technology will not allow us to reach any of these planets.

Based on the investigations and learning throughout the unit, students construct an argument based on evidence and reasoning about which exoplanet is the most Earth-like.

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-ESS1-1 **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.**
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.
Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.

In NYS, all occurances of the term "sun" in this PE have been formatted as "Sun."

HS-ESS1-3 **Communicate scientific ideas about the way stars, over their life cycle, produce elements.**
Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.
Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.

In NYS the clarification statement has been edited as follows: Emphasis is on the way nucleosynthesis varies as a function of the mass of a star and the stage of its lifetime.

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 1 focuses primarily on ideas related to composition and processes occurring inside the Sun and other stars, and how planets orbit around stars. These ideas fall within Core Idea ESS1 of the NGSS/NYSSLS, *Earth's Place in the Universe*. This unit also introduces students to the SEP of Engaging in Argument from Evidence and has a secondary focus on the SEP of Developing and Using Models. 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 *Patterns*, which fits well with our selected SEP and the understanding that we can use patterns found in data collected here on Earth to make claims about the behavior of distant objects in space. Two secondary CCCs for the unit, Scale Proportion and Quantity, and Stability and Change, are also useful to students as they use these ideas in two ways: (1) developing models that address how the Sun has been able to provide Earth with the right amount of energy for a long time in order to sustain life; (2) making claims about whether exoplanets can sustain life, based on the stability of their nearby stars and the stability of water given the shape of their orbit. 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 1

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
Asking Questions and Defining Problems	ESS1.A The Universe and Its Stars	Patterns
Developing and Using Models	ESS1.B Earth and the Solar System	Scale, Proportion, and Quantity
Using Mathematics and Computational Thinking	PS3.D Energy in Chemical Processes and Everyday Life	Systems and Systems Models
Constructing Explanations and Designing Solutions	PS4.B Electromagnetic Radiation	Energy and Matter
		Stability and Change

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 since all of the exoplanets in Unit 1 come from different solar systems within the Milky Way galaxy. 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 planetary motion.

ESS1.B Earth and the Solar System

- Students in middle school learn that the solar system was formed due to the pull of gravity on a disk of dust and gas. They also learn that planets and other objects in our solar system all orbit our Sun due to the pull of gravity. This understanding of the role of gravity will help them when they learn about the opposing forces of nuclear fusion and gravity inside stars.

PS3.D Energy in Chemical Processes and Everyday Life; PS4.B Electromagnetic Radiation

- In middle school, students learn foundational concepts about light, heat and energy transfer (including radiation), and the nature of matter and atoms that will support them throughout this unit.

Crosscutting Concepts from Middle School

Patterns

This unit builds on the following aspects of Patterns in middle school:

- Middle school students learn that patterns in data can be identified in graphs and images, and that these patterns can be used to identify cause and effect relationships. Students in middle school also learn that macroscopic patterns observed are related to what is happening at the microscopic level, which will be important in helping them understand how observations related to the huge scale of stars can be explained using patterns at the atomic scale (fusion).

Science and Engineering Practices from Middle School

Developing and Using Models
● Students in middle school have experience developing models based on evidence, developing models to describe unobservable mechanisms, and using models to make predictions. The use of modeling in this unit at the high school level builds on these experiences as students have to develop explanatory models based on data gathered across the unit to show the relationships between components of a system (such as inside the Sun and between the Sun and the Earth).

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. While all other Science and Engineering Practices students engage within this unit are aligned with the NGSS at the high school level, because this is the first unit of this course, opportunities to engage with the practice of Arguing from Evidence were intentionally designed at the middle school level. This was done so that students can apply what they learned about argument at the middle school level while working toward developing proficiency around high school level elements of the two Science and Engineering Practices foregrounded in this unit.

Assessment

Performance expectations (PEs) in the NGSS describe what students should know and be able to do. Unit 1 targets a bundle of three PEs taken from the first core idea in high school Earth and Space Science (ESS1), Earth's Place in the Universe; those standards are HS-ESS1-1, HS-ESS1-3 and HS-ESS1-4. 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 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:

	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E
Developing and Using Models	✔	✔	✔
Using Mathematics and Computational Thinking			✔
Constructing Explanations and Designing Solutions	✔	✔	
ESS1.A The Universe and Its Stars	✔	✔	
ESS1.B Earth and the Solar System			✔
PS3.D Energy in Chemical Processes and Everyday Life	✔	✔	
PS4.B Electromagnetic Radiation	✔		
Patterns	✔	✔	✔

	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E
Scale, Proportion, and Quantity	✔		✔
Energy and Matter		✔	
Stability and Change		✔	

At the end of Unit 1, 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 1 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

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.

Standards for Mathematical Content

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

HSA-CED.A.4 Algebra	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law V = IR to highlight resistance R.
HSA-SSE.A.1 Algebra	Interpret expressions that represent a quantity in terms of its context. a. Interpret parts of an expression, such as terms, factors, and coefficients. b. Interpret complicated expressions by viewing one or more of their parts as a single entity. For example, interpret P(1+r)^n as the product of P and a factor not depending on P.

Common Core State Standards (ELA/Literacy)

Speaking and Listening Standards

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.
SL.9-10.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

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.9-10.7	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.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.

Implementing Unit 1

This unit should be completed during the first month or two of school. 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 Unit 1 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	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E	Unit Closing
Class Consensus Discussion		1	1		
Class Consensus Model				1	
Domino Discover	1	1	4	2	
Idea Carousel		1	1	1	
Rumors		1		1	
Think-Talk-Open Exchange			1	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	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E	Unit Closing
Claim-Evidence-Reasoning (CER)		1			
Sequence Chart		1			

	Unit Opening	How the Sun Works 5E	Star Life Cycles 5E	Planets and Orbits 5E	Unit Closing
Text Annotation			1	2	

Simulations in this Unit

Lesson	Simulation Title	Source	Technical Notes	Permissions Notes
How the Sun Works 5E	Three Views Spectrum Demonstrator Simulation	https://www.google.com/url?q=https://astro.unl.edu/classaction/animations/light/threeviewsspectra.html&sa=D&source=docs&ust=1751987390895118&usg=AOvVaw2bEyiNlgHlbBAzf7QBsJzo	NA	NA
Star Life Cycles 5E	Star in a Box Simulation	https://www.google.com/url?q=https://starinabox.lco.global/%23&sa=D&source=docs&ust=1753241161441319&usg=AOvVaw0pXXPFzYOwXLRpAjoaOAmp	NA	NA
Star Life Cycles 5E	Iron [26] Game	https://dimit.me/Fe26/	NA	NA
Planets and Orbits 5E	Exoplanet Detection: the Transit Method Transit Method Different Planet Sizes Transmit Method Multiple Planets What's a Transit?	https://science.nasa.gov/resource/exoplanet-detection-transit-method/	NA	NA

Videos in this Unit

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Opening	Planet Earth II Trailer	https://www.youtube.com/watch?v=c8aFcHFu8QM&t=3s	NA	NA

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Opening	How Many Planets are in the Milky Way?	https://www.youtube.com/watch?v=d9x9RRc0RoU&t=2s	NA	NA
How the Sun Works 5E	NASA Footage of the Sun	https://www.youtube.com/watch?v=UJTo1Hc8fAk	NA	NA
Star Life Cycles 5E	Supernova 1054 - Crab Nebula remnant	https://www.youtube.com/watch?v=aysiMbgml5g	NA	NA
Star Life Cycles 5E	Star Formation by Collapse of Molecular Clouds	https://www.youtube.com/watch?v=YbdwTwB8jtc	NA	NA
Star Life Cycles 5E	Stephan Hawking - Supernovas	https://www.youtube.com/watch?v=tXV9mtY1AoI&t=1s	NA	NA
Planets and Orbits 5E	Comet Borrelly Flyby	https://www.jpl.nasa.gov/videos/comet-borrelly-flyby/	NA	NA
Planets and Orbits 5E	Classroom Demonstration: Elliptical Orbits	https://www.youtube.com/watch?v=ciEDPkc6vKE	NA	NA

Lab Materials in this Unit

Lesson	Lab	Materials needed (per group)

Other Materials in this Unit

Lesson	Materials needed
Unit Opening	❑ *Initial Model* student work ❑ *Telling the Story* student work ❑ Post-it notes ❑ Chart paper
How the Sun Works 5E	❑ Sticky notes ❑ Chart paper ❑ *Investigating Light from the Sun Student Work* (sample student work) ❑ *Spectra Sequence Chart* ❑ *Spectra Sequence Chart Student Work*] ❑ *Determining the Composition of the Sun Student Work* ❑ Classroom resource *What Counts as an Evidence-Based Claim?* ❑ *Claim and Data Cards* ❑ *Claim and Data Cards Example Student Work* ❑ *Constructing an Evidence-Based Argument Student Work* ❑ Driving Question Board ❑ Group's initial models from Unit Launch (chart paper) ❑ *Connect to the Performance Task: How the Sun Works Student Work*
Star Life Cycles 5E	❑ *What Kinds of Stars Have Long and Stable Life Spans? Student Work* ❑ *HR Diagram Star Circles* ❑ *HR Diagram Graph Template* ❑ *How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans? Student Work* ❑ *Why do some stars not fall in the main trend line?* ❑ Natural Reader Text to Speech ❑ *How and Why do Stars Change Student Work* ❑ Driving Question Board ❑ Groups' revised models (charts) ❑ Class wide evidence-based claim poster ❑ *Performance Task Organizer Student Work*
Planets and Orbits 5E	❑ Sticky notes ❑ Computers with Excel or Google Sheets ❑ Excel Spreadsheet for Planet Data Analysis Graphing ❑ *What are orbits like in our solar system? Student Work* ❑ Computers with Excel or Google spreadsheet ❑ Kepler's Third Law Calculator ❑ *Which Exoplanets Stay Within the Habitable Zone Example Class Response* ❑ Driving Question Board ❑ Groups' revised models (charts) ❑ Class wide evidence-based claim poster ❑ *Connect to the Performance Task: Planets and Orbits Student Work*

Lesson	Materials needed
Unit Closing	❑ Driving Question Board

Teacher Materials for Unit 1

Unit Opening

What has made Earth able to sustain life? If we are not successful in stopping the negative changes to planet Earth, is there an exoplanet that is Earth-like enough to sustain life?	**Performance Expectations** HS-ESS1-1, HS-ESS1-3, HS-ESS1-4	**Anchor Phenomenon** Out of all of the planets in the solar system, only Earth has life! Earth didn't have life for a long time, and now it does	**Time** 2 days

Earth has been an ideal place for humans and other life to be sustained for 12,000 years. Now rising global temperatures have caused sea levels to rise, and an increase in floods and droughts, all forcing groups of people to leave their homes. There is also a rapid decline in populations of species worldwide that many scientists are referring to as the "Sixth Mass Extinction." Earth is becoming less and less welcoming due to human impact, and our population is continuing to increase.

ANCHOR PHENOMENON	What is it about Earth that makes it the only planet in our solar system that has sustained life?	Out of all the planets in the solar system, Earth has life! Earth didn't have life for a long time and now it does.
PERFORMANCE TASK	A rise in global average temperatures is making Earth less and less habitable!	Throughout the unit students investigate what has made Earth the only planet in our solar system that can sustain life. After each investigation, students will consider what they have learned and will revise their initial models. They will use their initial models to help analyze and interpret data from stars and planets in other solar systems in order to write an argument from evidence about which exoplanet is most likely to be habitable.
DRIVING QUESTION BOARD	What questions do we have?	Based on their initial ideas for why planet Earth is the only planet in our solar system that has been habitable, students formulate a driving question board that will drive unit instruction.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

What is it about Earth that makes it the only planet in our solar system that has sustained life?

Out of all the planets in the solar system, Earth has life! Earth didn't have life for a long time and now it does.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs ❑ groups of four	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Life in the Solar System Timeline ❑ Life in the Solar System ❑ Initial Model ❑ Tell the Story	None	❑ *Initial Model* student work ❑ *Telling the Story* student work ❑ Planet Earth II Trailer

Surfacing Student Ideas

1. Show Planet Earth II Trailer to the class and have students note observations in response to the prompt below.
    - Identify or describe 2-3 species and the environment in which each lives.
2. Have several students share out their responses. Students will name or describe a range of species. Leverage their responses by highlighting the abundance of different species on Earth, then raise the question of whether there is life elsewhere in the solar system.
3. Distribute the *Life in the Solar System Timeline* and *Life in the Solar System*, and have students work in pairs to respond to the prompts.
4. For each question, have a few pairs of students share out their responses.

Access for All Learners

All learners have seen species in this Planet Earth II video or similar species in previous classes, in video or in person, so they can all make some connection to the video. Students may not know the name of some species, so be sure to emphasize that they only need to describe the species the best they can.

Look & Listen For

Students may generate a range of ideas. The following ideas may come up and are important for transitioning to the next step:

- It took over a billion years for the first life to appear on Earth and even longer for more complex life to appear
- The first life did not appear on Earth until several hundred million years after the formation of oceans and an atmosphere
- There is no evidence for life anywhere else in the solar system, only evidence of water

5. After students have surfaced responses, transition to the next step by saying: “Out of all the planets in the solar system, Earth has life! Earth didn’t have life for a long time and now it does. So what is it about Earth that makes it the only planet in our solar system that has sustained life?”

6. Introduce the term habitable as a place that is suitable for life.

7. Provide students with the *Initial Model* and have students complete it independently or in pairs. Then, have students work in groups of four to collaboratively develop an initial model for why Earth is the only planet in our solar system that has been habitable on poster paper.

8. Transition to the next step by saying: “While Earth has been habitable for a long time now, scientists are concerned about the stresses Earth has been experiencing in recent decades and what it means in terms of its capacity to sustain life as we know it in the future.” Tell students that you are going to show a video and provide three texts that the class can use to collaboratively tell the story of what is currently happening to planet Earth.

Conferring Prompts

Confer with students as they create their model.

- Are there arrows or labels you want to add to your drawing?
- What process do you think this shows?
- Are there any parts of your diagram that require terms or descriptions in order for others to understand?
- Are there any important cause and effect relationships you want to make clear to others?
- Are there any relationships between components that might not be clear to others?
- Why did you decide to include this component in your model?
- Are there any other components of the system you’re modeling that might be important to explain this phenomenon?

Implementation Tip

This is the first time students have modeled why they think the Earth is habitable. The Earth-Sun System template is useful for steering students toward modeling at the scale of our solar system, which is the scale at which students will be investigating and modeling Earth's habitability throughout the unit. Moving forward, do not provide this template unless a student or group seems confused about how to start their revised versions of their model.

Telling the Story

1. Show The Hidden Impacts of Climate Change to the class and have students note observations related to the following prompt:
    - What are the important details from the video that tell the story of what is starting to happen to planet Earth?

2. Distribute *Tell the Story* to the class and have students read and annotate the text, looking for important details. Prompt students to read the texts through one time before going back to do annotations. Remind students to focus on the phenomenon, not their predictions/hypotheses about what is going on.

3. Have students discuss with their group to identify the five most important details from the video and text, then develop a consensus about the overall story of what is happening to planet Earth.

Conferring Prompts

Confer with students as they annotate the texts and tell the story.

- What is happening to planet Earth?
- 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?

Differentiation Point

It may be helpful for some students if you break down the steps for working independently. Have them read through the texts first, without writing. Then have them read through them a second time, with annotations either in the margin of the page or on a sticky-note. Remind students to focus on the information provided, not on their predictions or hypotheses about what is going on.

Brainstorm Possible Solutions

1. Have students independently brainstorm possible solutions that will ensure the survival of the human species. Provide the following guiding prompts:
    - What are your initial ideas for what we can do to ensure the survival of humans and other species?

- What if humans and many other species on Earth today can no longer live on Earth? What can humans do to survive as a species if we are not successful in stopping the negative changes to planet Earth?

2. Put students in groups of four to share their solutions and select two solution ideas they would like to share with the rest of the class.

3. Use the Group Learning Routine, Domino Discover, to have groups share out their ideas as you chart them.

4. Students are likely to name a range of possible solutions, including finding another planet or moon for humans to live on. The solution of finding another planet will be the focus of the performance task that drives instruction in the unit. If students do not name this solution, tell them that this is one solution that scientists are exploring, just in case we cannot ensure the survival of the human species here on Earth.

Implementation Tip

This may be the first time Domino Discover is being used in this unit (depending on whether you used it in the Anchor Phenomenon Launch!). This 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 Earth & Space Science Course Guide for support with this routine.

Performance Task

A rise in global average temperatures is making Earth less and less habitable!

Throughout the unit students investigate what has made Earth the only planet in our solar system that can sustain life. After each investigation, students will consider what they have learned and will revise their initial models. They will use their initial models to help analyze and interpret data from stars and planets in other solar systems in order to write an argument from evidence about which exoplanet is most likely to be habitable.

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Introducing the Performance Task	None	❑ How Many Planets are in the Milky Way?

Launch the Performance Task

1. Remind students that they shared many possible solutions for ensuring the survival of the human species. Let them know that in this unit they will have the opportunity to explore one of their proposed solutions, finding another Earth-like planet for humans to live on.

2. Provide students with the handout *Introducing the Performance Task* and provide time for students to read it. Then allow students the opportunity to ask any clarifying questions about the performance task.

3. Tell students you're going to show them a video that will give them some information about planets that are out there for them to investigate. Show the first two minutes and fifty seconds of the How Many Planets are in the Milky Way? .

4. After watching the video, highlight for students that there are a tremendous number of planets that they can investigate, so they will have to come up with a criteria for what makes a planet Earth-like in order to narrow down the search.

5. Remind students that they already began to develop this criteria when they developed their initial model for why Earth is the only planet in our solar system that has been habitable.

Driving Question Board

What questions do we have?

Based on their initial ideas for why planet Earth is the only planet in our solar system that has been habitable, students formulate a driving question board that will drive unit instruction.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table groups	None	None

Materials

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

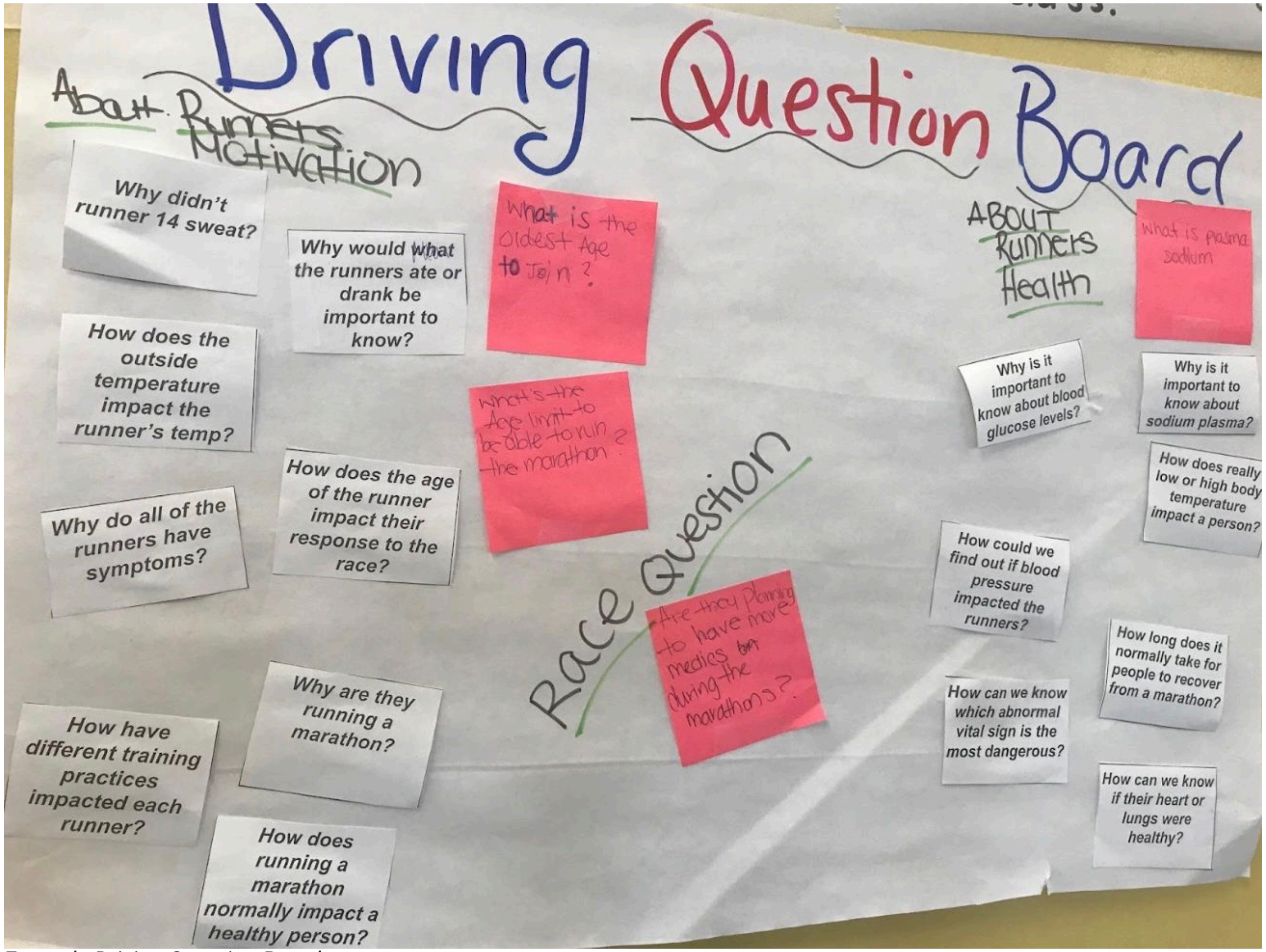
Developing Questions

1. Introduce the prompt below:
    - What do we need to investigate about other stars (suns) and planets in order to find an Earth-like planet where humans and other species might be able to live?

Think about your initial explanations for why planet Earth has been able to sustain life. Then generate questions you would like to further investigate about exoplanets and the stars at the center of their solar system.

2. Have students independently come up with questions they would need to answer in order to understand if an exoplanet was Earth-like. Each question goes on a separate sticky note.
3. In small groups, have students share and categorize their questions, then organize the questions onto pieces of chart paper.

Note: This step can also be completed as a whole-class activity, if that makes more sense.



Example Driving Question Board

Implementation Tip

Conferring Points
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?

Differentiation Point

If this is the first time students have generated a Driving Question Board (DQB) they may struggle with coming up with appropriate scientific questions. If so, provide students with the *DQB Cards* that can serve as an example or starting point. If using the scaffolded question set, encourage each individual or group to generate some questions on their own.

For more guidance on using the DQB throughout the unit, see the Earth & Space Science Course Guide.

Standards in Unit Opening

Performance Expectations

HS-ESS1-1 **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.**
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.
Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.

In NYS, all occurances of the term "sun" in this PE have been formatted as "Sun."

HS-ESS1-3 **Communicate scientific ideas about the way stars, over their life cycle, produce elements.**
Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.
Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.

In NYS the clarification statement has been edited as follows: Emphasis is on the way nucleosynthesis varies as a function of the mass of a star and the stage of its lifetime.

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
Asking Questions and Defining Problems • Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. SEP1(1)		

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task
Asking Questions and Defining Problems	Questions on the Driving Question Board		

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task
Mathematics			
ELA/Literacy			

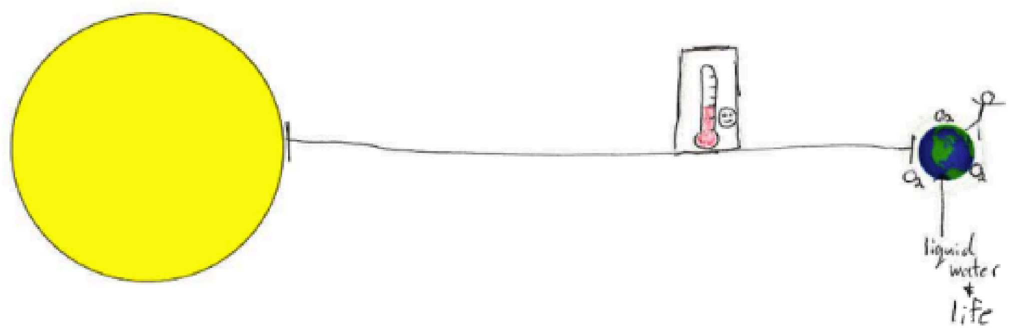
Student Work for Unit Opening

Example Student Work

Anchor Phenomenon: Initial Model

Why is Earth the only planet in our solar system that has been able to sustain life? Represent your initial ideas about what makes Earth habitable in the space below.

The Earth-Sun System



Explain your model. Describe your diagram in words as best as you can.

Earth is the only planet in our solar system that has been able to sustain life because its distance from the Sun gives it just the right temperature. It also has an atmosphere with oxygen and liquid water for life to survive. Other planets are too far or too close to the Sun and don't have enough liquid water or an atmosphere.

Example Student Work

What is the overall story of what is happening to Earth?

Important details our group surfaced (provide at least 5):

1. Earth is getting warmer as carbon dioxide increases.
2. Species are rapidly going extinct.
3. Seal-level is rising due to global warming and cities could end up underwater.
4. The increasing population on Earth means all our resources are being used up.
5. Insects and disease carriers such as mosquitoes and ticks might be more common in New York as temperatures increase.

Overall Story (based on group discussion):

Earth is basically becoming a place that is less habitable. As there are more and more people, carbon dioxide increase is causing global warming, which is causing sea-level to rise, species to go extinct, and insects and disease carriers such as mosquitoes and ticks might be more common in New York as temperatures increase. All of these things are very harmful and dangerous for life. Earth is no longer as good of a place for us to live.

Classroom Resources for Unit Opening

DQB Cards

Does the planet have a sun?	*Is there air or an atmosphere on the planet?*	*What is gravity like on the planet?*
What kind of weather does the planet have?	*Is there water on the planet?*	*Does the planet already have life on it?*
Is the planet near a black hole?	*How far is the planet to the nearest star?*	*What kinds of living things can the planet sustain?*
Does the planet have day and night?	*Are there seasons on the planet?*	*What is the landscape of the planet like?*
Does the planet have a moon?	*What is the temperature like on the planet?*	*How fast is the planet moving?*
How long has the planet existed?	*Does the planet have stable conditions for life to exist?*	

How the Sun Works 5E

Why is the Sun so important to life on Earth? How does the Sun work? How has the Sun provided us with the right amount of energy for life to exist?

Performance Expectations
HS-ESS1-1

Investigative Phenomenon
Energy released by the Sun in one second is more energy than the entire world uses in a whole day .

Time
6 days

In this 5E instructional sequence, students are investigating the questions about the Sun surfaced during the Driving Question Board launch, such as Does the exoplanet have a Sun like ours? This leads to questions about how our Sun is able to provide light and heat to support life on Earth. Students use different kinds of evidence to arrive at conclusions about the composition of the Sun and the processes that release energy inside the Sun, helping them understand how life on Earth is able to receive that energy.

ENGAGE	How Does the Sun Provide Energy?	Connecting to their earlier questions about finding an exoplanet that has a star like our Sun and their ideas about how the Sun provides light and heat for life on Earth, students share their initial **claim** for **how the Sun is able to release energy** on a **large scale** and express a need to investigate the Sun further to figure out its composition and how it works.
EXPLORE	Investigating light from the Sun	Students use a simulator to figure out how a spectroscopy telescope works. They then analyze and interpret a data set (**light spectra from the Sun and laboratory references of gas light spectra**), **looking for empirical evidence of patterns** that either refutes or supports their **initial claims**.
EXPLAIN	Developing a claim about the Sun's composition	Using what they know about the behavior of light when it passes through different materials, students use **patterns identified from empirical evidence** in **light spectra** as **evidence to support a claim** about our **Sun's composition**.
ELABORATE	Using additional evidence to construct a scientific explanation about the mechanism of energy released by the Sun	Students **use the evidence** related to **scale (duration and quantity)** of **energy released by the Sun** to **construct a scientific explanation** about the process that **is releasing the energy received by Earth**.
EVALUATE	Developing explanatory and predictive models of the Sun	Students **revise and critique their models** for why Earth has been such an ideal place for life to exist and evolve using **empirical evidence of patterns** in the **Sun's spectra** and lab samples of elemental gases and comparisons of **scale (duration and quantity)** of **energy released by the Sun**. Students **use their model** of our Sun **to predict how the relative proportions of hydrogen to helium changes as the Sun ages** and what that means for the future stages of our Sun.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How Does the Sun Provide Energy?

Connecting to their earlier questions about finding an exoplanet that has a star like our Sun and their ideas about how the Sun provides light and heat for life on Earth, students share their initial **claim** for **how the Sun is able to release energy** on a **large scale** and express a need to investigate the Sun further to figure out its composition and how it works.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ None	❑ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
❑ How Does the Sun Provide Energy	None	❑ Sticky notes ❑ Chart paper ❑ NASA Footage of the Sun

Launch

1. Remind students that during the Driving Question Board launch, one category of questions that emerged was related to the Sun (for example, *Does the exoplanet have a sun like ours?*). Ask students to share more about why they asked these questions. Listen for answers that highlight how the Sun is essential for life because it provides us with heat (not too cold/hot) and light for plants to grow (something about food).

2. Tell students that in order to figure out whether the exoplanet has a sun like ours, we need to make sure we understand what our Sun is like! This is why we will investigate how it works.

3. Tell students that to start investigating how the Sun works, they can surface what they know about the Sun, from experience. Ask them to imagine the Sun and independently jot down what comes to their mind.

Look & Listen For

Possible responses:

- It's very bright.
- It's yellow or white.
- It's very large compared to Earth.
- It's very hot.

4. Tell students that you are going to show NASA footage of the Sun that was obtained through a telescope that enhances images of the Sun in a way that allows us to see more details of its appearance and behavior, and that part of that enhancement makes the Sun appear colors other than its actual color, yellow. Show the NASA footage of the Sun video and ask students to make additional observations.

Look & Listen For

Possible additional responses:

- It looks like lava.
- It has flames shooting out of it .
- There're explosions in it.
- Some parts are darker than others.
- It seems to have gas in it.

Surfacing Student Ideas

1. Have students read the investigative phenomenon for this 5E sequence, found at the top of *How Does the Sun Provide Energy*.

2. Have students turn to a partner and discuss the following prompt about related phenomena: What other phenomena are you familiar with that are associated with a lot of energy? How is that energy being produced?

3. Then ask students to independently brainstorm ideas in response to the following prompts:
   - What are your ideas for how the Sun provides so much energy?
   - What did you observe in the video or in your life that made you think this?
4. Each student reads through their ideas and observations those ideas are based on, and decides what idea/observation they feel most confident about, writing that one idea/observation on a sticky note. This should be a response to the question: *How does the Sun work?*

5. Use the Group Learning Routine **Rumors** to surface student ideas.

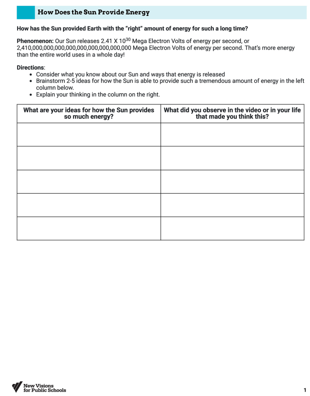
6. After students have shared their ideas through Rumors, categorize student ideas in order to address during the instructional sequence. See the Example Poster for possible categories.

7. Students are likely to have a range of ideas. Tell students that the class will need to investigate further in order to make conclusions about how the Sun is releasing so much energy. Ask students how they normally figure out how something works. Listen for answers about taking something apart, learning what it is made of, and figuring out how the parts work together for it to function.

Access for All Learners

While all students have some background knowledge on the topic of the Sun, it's likely some have not thought a lot about how the Sun produces energy. Asking students to think about a similar phenomenon they are familiar with will help them connect to ideas about energy they already know. This will help all students generate initial ideas about how the Sun works and make it more relevant to their own lives.

8. Ask students how they think we can investigate further, prompting them to consider what we can observe about the Sun from Earth and how we can observe it. Listen for answers about light and energy and the use of a telescope.



How Does the Sun Provide Energy

How has the Sun provided Earth with the "right" amount of energy for such a long time?

Phenomenon: Our Sun releases 2.41 X 10^{30} Mega Electron Volts of energy per second, or 2,410,000,000,000,000,000,000,000,000,000 Mega Electron Volts of energy per second. That's more energy than the entire world uses in a whole day!

Directions:
- Consider what you know about our Sun and ways that energy is released
- Brainstorm 2-5 ideas for how the Sun is able to provide such a tremendous amount of energy in the left column below.
- Explain your thinking in the column on the right.

What are your ideas for how the Sun provides so much energy?	What did you observe in the video or in your life that made you think this?

Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the title *How does the Sun work?*

Routine

This is the first time the routine **Rumors** appears in this unit! Rumors is a routine designed to surface all students' initial ideas in a low stakes manner. After having an opportunity to independently brainstorm, students identify the idea they are most confident about and share it with several classmates. Students listen for trends in their thinking and at the end of the routine share those trends with the rest of the class including the teacher. Please read the Unit 1 Guide for detailed steps about this routine.

Access for All Learners

All students have some background knowledge on the topic of the Sun, including scientific and non-scientific ideas from diverse cultural backgrounds. Be sure to provide opportunities for students to articulate those ideas at this point, by documenting ideas that make sense to them. Establishing where student thinking is, allows both learners and the teacher to track how ideas are changed or refined as new information arises.

Look & Listen For

Students have background knowledge that can be used to drive the investigation. Listen for the following ideas related to energy and its conservation that students grappled with in middle school:

- The Sun is a burning ball of gas.
- There are explosions happening inside the Sun.
- The Sun is made of chemicals (they may say hydrogen or helium) that are reacting and those reactions produce energy.
- The energy is potential energy stored in atoms and molecules the Sun is made of. (MS.PS1.B, CCC #5 MS element)
    - *At the beginning of the Elaborate phase, the ideas related to chemical reactions and explosions can be leveraged to introduce the Elaborate task which asks students to consider two types of reactions involving hydrogen, chemical combustion and nuclear fusion, as possible processes that can account for the scale of energy released by the Sun.*
    - *During the Elaborate phase, students will consider the idea of scale of energy and should be able to conclude that while they are correct about the fact that energy from the Sun comes from potential energy stored in atoms, only nuclear reactions can account for the amount of energy released by the Sun.*

Listen for the following ideas related to energy and its conservation that students grappled with in middle school:

Students may surface these ideas (and others!) about investigating the Sun and about the potential uses of technology for science learning:

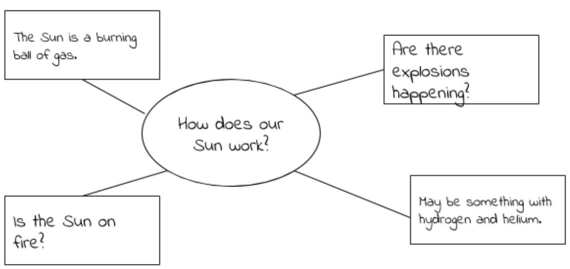
- Study the Sun's light waves (MS.PS4.B)
- Use a space based telescope
- Look for patterns in data from space instruments (CCC #1 MS element)
- Use a prism

Integrating Three Dimensions

You do not need to explicitly mention **CCC #3 - Scale, Proportion, and Quantity** here; however, listen for student thinking about this idea. Students will figure out over the course of the 5E sequence that chemical reactions do not produce enough energy for a long enough time to explain how the Sun works.

9. Use the students' responses to introduce the idea that scientists use an instrument called a spectrometer to get more information about light, and they have special telescopes that are used to observe the light from objects in space like the Sun.

10. End the discussion by telling them that they will next be conducting an investigation of sunlight to see if they can figure out what the Sun is made of and how it works.



Implementation Tip

Students may be familiar with the idea that we can use a telescope to *look at* the Sun, but not the idea that we can use that information to make conclusions about the inside of the Sun. This Engage phase supports students in recognizing that “take it apart and look inside” isn’t sufficient for objects that are very far away.

Explore

Investigating light from the Sun

Students use a simulator to figure out how a spectroscopy telescope works. They then analyze and interpret a data set (**light spectra from the Sun and laboratory references of gas light spectra**), **looking for empirical evidence of patterns** that either refutes or supports their **initial claims**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Groups of 2-3 students	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Investigating Light from the Sun	None	❑ *Investigating Light from the Sun Student Work* (sample student work) ❑ Three Views Spectrum Demonstrator Simulation

Launch: What is an Investigation?

1. Remind students that, at the end of the Engage phase, they surfaced the idea that we cannot investigate the Sun by actually taking it apart. We have to observe it from far away.

2. Preview for students the flow of the investigation for this Explore phase. First, we will learn about a tool for observing the Sun from far away, then we will look at data gathered with that tool.

3. Ask students to consider what makes this process an **investigation.** We can come back and discuss this at the end of the activity.

Implementation Tip

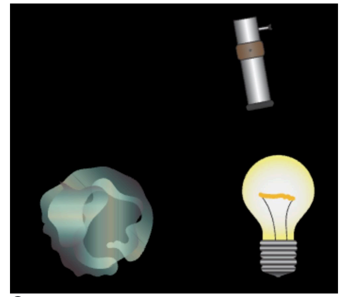
While students have certainly encountered the word **rainbow** before, they may not remember that **spectrum** (pl. **spectra**) is the term for the set of colors into which light is broken. Since this is not a term around which we are sense-making in this 5E, it is fine to remind students of this term as they do the simulation.

Access for All Learners

Some students may have very little or no experience with a spectrometer. If spectrometers are available, have students observe light through them and have several students share out about what they observe. This real life experience will help even the playing field and support all students in making sense of the Three Views Spectrum Demonstrator.

Investigating Light from the Sun

Part 1: What does a spectrometer tell us about light?



Spectrometer

1. Provide each student with the *Investigating Light from the Sun* handout. Each group should have a laptop to navigate to the Three Views Spectrum Demonstrator.
2. Launch students into working on questions 1-4 as they work with the simulator.
3. Support students in using the simulation, keeping in mind that it is important for them to make sense of what they are observing independently.
4. Since the simulator has the word "spectrum" in its name, students may be prompted to remember what a spectrum is. If not, it is fine to remind them of the concept of spectra and rainbows, which is something they are likely to have covered at least once since elementary school.

Look & Listen For

There are several ways students may describe their thinking in Question #4. Some possible responses that show students are making sense of the simulation in a way that will help them figure out the difference between light from the lightbulb and from the Sun include:

- The stuff in the dust cloud blocked some of the light. That's why you see black lines.
- No matter where the light comes from, the colors in the spectrum are in the same order.
- When the light from the bulb passed through the dust cloud, it was interrupted, so it looks like that with black lines.
- Something is blocking parts of the light so we don't see the whole rainbow.
- Some of the light looks like it got trapped in the dust cloud.

5. If students are having trouble arriving at some of the ideas above, use the suggested conferring questions at the right to support their sensemaking process. They will also be able to build on these ideas in parts 2 and 3 of this investigation and the Explain phase.

Conferring Prompts

Confer with students as they work in collaborative groups to make sense of their observations.

- What happened to the white light when it passed through the spectroscopy telescope?
- Does the spectra of the white light look the same when it passes through the hydrogen gas?
- Was all light able to pass through the hydrogen gas?
- What do you think happened to the missing light?
- What do you think caused what you observe?

Part 2: What do we see when we observe the Sun with a spectrometer?

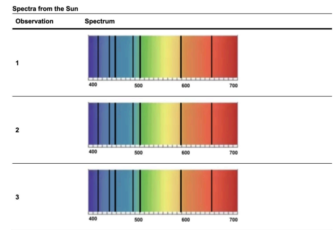
Integrating Three Dimensions

This is the first point where students are prompted to consider one of the unit's foregrounded crosscutting concepts, **CCC #1 - Patterns.** In this phase, introduce the CCC through the prompt about interpreting data. If students do not cite the numbers (wavelengths) under the black lines are the same in each spectra as empirical evidence of the pattern, ask them to cite evidence that the black lines are in the same place, as needing empirical evidence to identify patterns is an important element of **CCC #1 - Patterns.** Then, in the Explain phase, students will use this CCC as a lens for other tasks.

This is also an opportunity to connect patterns in evidence to **SEP #6 - Constructing Explanations and Designing Solutions**. This task supports students in building an understanding that claims are based on empirical evidence.

1. Launch students into observing patterns in the spectra, then answering questions 1-2.

While it may seem obvious that the Sun's light would be the same no matter when an observer is looking at it, this activity is important for highlighting the fact that we have *evidence* for this consistency. No matter when we observe the Sun, or the location from which we observe it, its spectra are consistent.



Look & Listen For

The experience of looking at spectra data provides experience with citing empirical evidence for patterns, which students will build on in the coming parts of this instructional sequence when they use the patterns as evidence for a claim about the Sun's composition. The two prompts are designed to support students
in developing the idea that empirical evidence is needed to identify a pattern (in this case a pattern in the Sun's spectra) and build toward a claim about the Sun's composition.

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

- The pattern in the black lines is identical in observations 1, 2, and 3. The evidence is that you can look at the numbers under the black lines and see they are the same
- The light from the Sun isn't changing; no matter how many times you observe it, the spectrum will always look the same
- Whatever the Sun is made of is blocking parts of certain colors, just like in the simulation

Routine

This may be the first time **Domino Discover** is being used in this unit (depending on whether you used it in the Anchor Phenomenon Launch!). This 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.

Access for Multilingual Learners

Using Domino Discover at this stage provides support for English Language Learners who are **emerging and transitioning ELLs.** Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development.

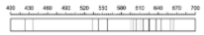
Part 3: How does the Sun's spectrum compare to the spectra from light passed through gases in a lab?

1. Launch students into observing patterns in the data from the gases in a lab to answer the two questions and have them record their answers and ideas in the **See-Think-Wonder** chart.

Look & Listen For

The See-Think-Wonder graphic organizer pushes students to make connections between the evidence and claims they can make. Students may give quantitative or qualitative descriptions in the "See" column at this stage, including:

- There are three trials or observations for each element
- Hydrogen has 4 black lines, helium has 3
- The sun's spectra has its own special arrangement of black lines, always above the same numbers
- Each element has its own special arrangement
- The black lines in each element's spectra appear above the same number (wavelength)
- Hydrogen samples always look the same. The same is true for the other samples
- The pattern of lines in the spectrum from the sun matches the lines in the spectra for helium and hydrogen gases
- We can figure out what is in a light source by looking at its spectra
- We can use this information to figure out what things are made of
- We think the sun might be composed of hydrogen and helium, but probably not the other elements

Gas	Sample 1	Sample 2	Sample 3
Hydrogen			
Helium			
Nitrogen			
Oxygen			

Conferring Prompts

Confer with students as they work in collaborative groups to make sense of the data and complete the See-Think-Wonder chart. Students may have forgotten that each sample is a gas; this detail is important to keep in mind in order to make sense of the data.
Discussions with students should push their thinking around citing empirical evidence to identify patterns, making connections, and using evidence to support their ideas.

- Was all light able to pass through each gas?
- What do you think happened to the missing light?
- What patterns do you notice in the sunlight data? What evidence do you have for that pattern?
- What do you think caused what you observe?
- What inferences do the laboratory observations allow you to make about how light behaves when it passes through different materials?
- How is the spectrum from each gas similar or different from the Sun's spectrum?

2. This is a good point to surface the understanding that students are developing in the room. Use the group learning routine **Domino Discover** to surface one key understanding from each group. Be sure to push students to cite empirical evidence for any patterns they

Look & Listen For

During the Domino Discover, here are some possible things students may say that indicate emerging understanding:

- There is a pattern in where black lines in the spectra appear for each element gas. The black lines in each element's spectra appear above the same number (wavelength).
- When light passes through each gas, the colors are absorbed/blocked differently, which is why we see different patterns of black lines for each one.
- The pattern of lines in the spectrum from the Sun match the lines in the spectra for helium and hydrogen gases.
- We think the Sun might be composed of hydrogen and helium, but probably not Lithium or Sodium.

3. If students don't surface one or more of the observations above, display the Three Views Spectrum Demonstrator, the spectrum from the Sun and/or element gases and use the suggested conferring questions from this Explore phase to have students surface those ideas. Once those observations are surfaced, the class is ready to move on to the Explain phase.

Differentiation Point

The data in this section of the unit takes the form of spectra that students are asked to interpret, in order to make claims about the makeup of the Sun. It is critical that students' struggle with the data is supported and not cut short. While it might be tempting to help students with completing the See-Think-Wonder or coming up with analyses, this will cut short their learning. Instead, encourage students to use a more concrete way to line up absorption lines. Students can even cut out the spectra for each element, to make it easier to visualize where things line up.

Explain

Developing a claim about the Sun's composition

Using what they know about the behavior of light when it passes through different materials, students use **patterns identified from empirical evidence** in **light spectra** as **evidence to support a claim** about our **Sun's composition**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Class Consensus Discussion	❑ Sequence Chart ❑ Claim-Evidence-Reasoning (CER)

Materials

Handouts	Lab Supplies	Other Resources
❑ Determining the Composition of the Sun ❑ Summary Task	None	❑ *Spectra Sequence Chart* ❑ *Spectra Sequence Chart Student Work*] ❑ *Determining the Composition of the Sun Student Work* ❑ Classroom resource *What Counts as an Evidence-Based Claim?*

Launch

1. Ask students to share their current thinking about what we are trying to figure out (*Does the exoplanet have a Sun like ours?*).
2. Tell students that, so far, many ideas have surfaced about what our Sun is like and how it releases energy. Point to the *How does the Sun Work?* classroom poster from the Engage phase.
3. Facilitate a class discussion around what constitutes an **evidence-based claim** using their common experiences during Engage and Explore phases as a reference.
4. Let students know that they will now try to use the data from their observations during the Explore phase as evidence either to support their initial ideas or to revise their thinking.

Classroom Supports

Refer back to the poster from the Engage phase entitled *How does our Sun work?*

Classroom Supports

Document student ideas and questions surfaced during class discussion, as these will be an important reference for discussions of evidence-based claims later in this unit.

Look & Listen For

Students may generate a range of ideas, some of them influenced by how they talk about evidence in humanities or history classes.

All student ideas can be recorded at this point; some may be ruled out later in the unit.

<u>What Counts as an Evidence-Based Claim?</u>

You found information from a book or a reliable source.

The evidence comes from an experiment or investigation you did.

The claim is not just someone's opinion.

Many scientists can agree on that interpretation.

Patterns in data can serve as evidence.

At this point, it is fine if students do not have a complete understanding of what constitutes an evidence-based claim. They will be able to refine their understanding throughout this 5E sequence and the unit.

Integrating Three Dimensions

Thinking about the role of evidence in making claims is a key part of **SEP #2 - Developing and Using Models and SEP#6 - Constructing Explanations and Designing Solutions**, the two main SEPs in this unit. This discussion is a great opportunity to elicit and document students' current thinking about evidence and argumentation. In the following activity, students engage in a process that supports an evaluation of evidence from spectra.

Organize Evidence for a Scientific Explanation Regarding the Sun's Composition

1. Tell students that they are now going to use the evidence and ideas they have gathered to make a claim about the Sun's composition and continue working toward an agreement about how the Sun works.
2. Provide students with a set of cards that correspond to the sunlight investigation they carried out. Tell them that their task is to look at the information and images on each card and decide how to sequence them in a way that would allow someone else to understand how you can determine the composition of the Sun.
3. As students work, support them in making sense of the information in the cards and putting things in order. An example completed sequence can be found at *Spectra Sequence Chart Student Work*.

Implementation Tip

This sequence chart activity might seem redundant, but teachers who tried these materials in their classroom found that students really needed this time to literally put together their understanding from the Explore phase. Without this activity, there is a risk that the teacher will just have to explain what happened *to* the students, instead of facilitating their sense-making.

Access for All Learners

Students who are **emerging and transitioning** language learners benefit from the opportunity to work with images and repeated structure in this activity.
Students who are **expanding language learners** have the opportunity to receive multiple types of input of ideas -- in print and through others' discussion. This supports their language development and access to engaging in science.

Differentiation Point

The cards for this sorting activity are color-coded. In order to scaffold the activity, some/all groups can be given only the blue shaded cards (see the figure below) to begin with. These are the first set of events to put into sequence. After a group has figured out this sequence, they can be given the other additional sets of cards, which follow a similar pattern. See the example sequence below for further support on how this might look.

Example Sequence Chart - Blue Cards Only

Look & Listen For

While students are engaged in Sequence Chart task, circulate and listen for these ideas:

- White light emitted from a source initially contains many wavelengths that correspond to different colors, but we cannot see all those colors unless the light passes through a prism.
- A spectroscopy telescope contains a prism that separates light into all wavelengths that are present.
- If white light passes through a gas, some wavelengths will be absorbed. The wavelengths absorbed are dependent on the composition of the gas.
- If white light passes through a prism after passing through a gas, the prism will separate the light into all the wavelengths that remain, allowing us to see what wavelengths that particular gas absorbs. This process can be repeated over and over with a known gas in the laboratory, and the light spectra will always show the same pattern of absorption.
- Since light released by the Sun passes through the gas the Sun is made of, we think some wavelengths are being absorbed.
- We can view the spectra of sunlight when it passes through the prism in a spectroscopy telescope and match that spectra with laboratory references in order to determine the composition of the Sun.

Construct a Scientific Explanation About the Sun's Composition

1. After all groups have completed the sequence chart, they are ready to work on putting it together into a scientific explanation. In middle school, students gained experience constructing explanations from multiple sources of evidence and applying scientific reasoning to justify why that evidence supports a claim. Ask students to construct explanations about the Sun's composition without a scaffold. This opportunity to practice an explanation without a scaffold is an important step toward developing proficiency with SEP #6 -Constructing Explanations and Designing Solutions. If students do need further support, see the differentiation point below.

2. As students work, confer with them to support their work towards an explanation.

Conferring Prompts

Confer with students as they work in collaborative groups to complete the Claim-Evidence-Reasoning chart. Use the sample responses (below) to guide your questions.

Suggested conferring questions:
These questions should support and push students' thinking about how they are using evidence to support a claim-based explanation.

- Remember how we used spectra to figure out the Sun's composition? Why does this finding tell us that the Sun is composed of hydrogen and helium?
- I see you cited a pattern as evidence, how do you know there is a pattern? How can you make that clear in your explanation?
- Go back to your sequence chart and underline the points that are most compelling for linking evidence to your claim. Why did you pick those points?

Differentiation Point

Differentiation Point: Scaffold
If any students are struggling to get started with their scientific explanation, have students synthesize their learning about the Sun's composition in a Claim-Evidence-Reasoning chart. Then have them use the ideas they capture in the organizer to write an explanation in paragraph form.

Differentiation Point: Extension Activity
If you have a real spectrometer in your classroom, challenge students that complete their explanations early and demonstrate mastery to investigate real samples of unknown gases with the real spectrometer and to determine the identity of each unknown based on their spectra. Have them share their claims with the rest of the class, prompting them to cite empirical evidence of patterns they used to identify the unknown gases if they don't do so initially.

Integrating Three Dimensions

Students are working toward proficiency around **SEP #6 - Constructing Explanations and Designing Solutions**. Since the claim is less open-ended, with a sentence starter provided, students really get a chance to focus on how they use evidence and reason about that evidence.

Students will be using patterns as evidence for their claim, which is a middle school element of **CCC#1 - Patterns**. Needing empirical evidence to identify a pattern is an important high school element of **CCC#1 - Patterns.** The conferring question about patterns is designed to support students in developing this high school element of patterns.

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 evidence-based claims. It is really important for us to get to some agreement on how we represent what we know about how the Sun works, 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' scientific 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 how the Sun releases energy. 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. 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.

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

5. Before table groups confer, prompt them to consider the role of Patterns in figuring out which claim is best supported. Some prompts you might provide are:
    a. How are patterns in the data used to craft one of these claims?
    b. How does the pattern of data in spectra help you understand the Sun as a whole?
    c. How can you ensure that others are convinced that the patterns you are citing are truly patterns?

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.

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

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

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

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

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.

Take Time for These Key Points

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

- The Sun is made mostly of hydrogen and helium. We know this from spectra data.
- We have used patterns in data to figure this out; that may be a useful lens for figuring out other things in space science.
- We could support our claim about their being patterns in the spectra for the Sun and element gases by pointing out that the black absorption lines always appear above the same wavelength number for each.

Note: The class has not gotten into the idea of nuclear fusion yet, but that is coming up!

1. 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 sunlight;
   b. changed based on our investigation of sunlight;
   c. added based on our investigation of sunlight.

8. Modify the list of student ideas about how the Sun works based on student responses.

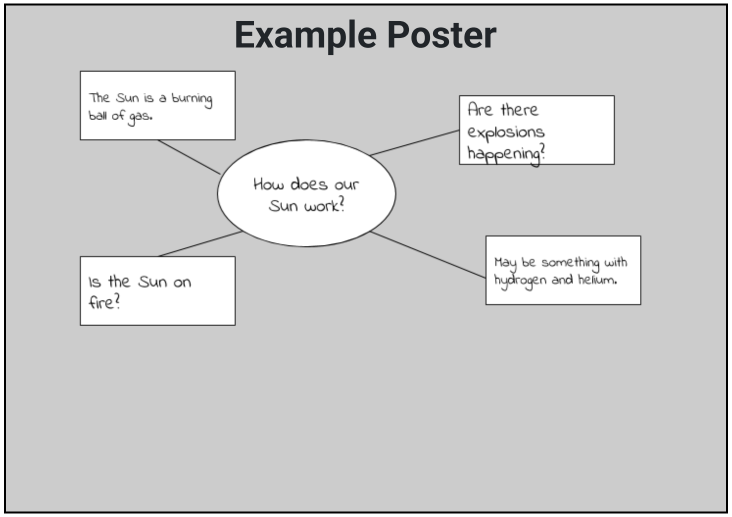
9. Return to student questions from the start of the 5E (the Engage), in order to bring up lingering issues not yet resolved, and new issues that have come up, such as:
   - Are hydrogen and helium on fire in the Sun? Or is something else happening?
   - Can gases burn?
   - People talk about the Sun "burning up"; does that mean it's actually burning?

Integrating Three Dimensions

The prompts about patterns in the Class Consensus Discussion are in support of students' consideration of **CCC #1 - Patterns**. The first two build upon middle school elements of patterns, while the third is meant to support students in developing the idea that empirical evidence is needed to identify patterns, an important high school element of patterns. They are modified from STEM Teaching Tools #41 (http://stemteachingtools.org/brief/41)

Access for All Learners

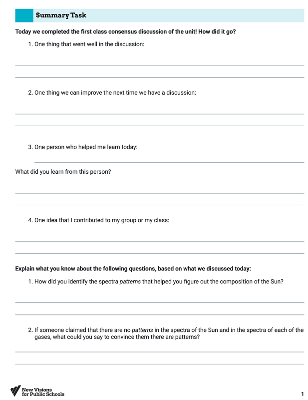
Rather than assigning a list of vocabulary words—a technique that rarely works for learning new vocabulary—this activity allows language learners to learn vocabulary from context, which may be particularly helpful for **transitioning** language learners, who already have some mastery of language.



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 circle back to the ideas in this text in the coming parts of the 5E lesson.



Summary Task

Today we completed the first class consensus discussion of the unit! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. How did you identify the spectra *patterns* that helped you figure out the composition of the Sun?

2. If someone claimed that there are no *patterns* in the spectra of the Sun and in the spectra of each of the gases, what could you say to convince them there are patterns?

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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**, the Sun's release of energy; 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

Using additional evidence to construct a scientific explanation about the mechanism of energy released by the Sun

Students **use the evidence** related to **scale (duration and quantity)** of **energy released by the Sun** to **construct a scientific explanation** about the process that **is releasing the energy received by Earth**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Our Sun: Chemical or Nuclear Energy? ❏ Constructing an Evidence-Based Argument	None	❏ *Claim and Data Cards* ❏ *Claim and Data Cards Example Student Work* ❏ *Constructing an Evidence-Based Argument Student Work*

Launch

1. Remind students that while they have determined that the Sun is composed of hydrogen and helium, they still do not know how those components release energy.

2. Let them know they will be considering two processes (nuclear and chemical) that involve hydrogen and/or helium and relate to their initial ideas in the Engage phase. These ideas may be things like:
   - The Sun is a burning ball of gas.
   - There are explosions happening inside the Sun.
   - The Sun is made of chemicals.

3. Present students with the task of analyzing data in the table Possible Energy-Releasing Processes in the Sun. They can use information in the table as evidence either to support their original claims or change their claims. The *Claim and Data Cards*, based on the data in that table, are designed to support this task. Tell them that, in order to identify data that counts as evidence for one claim vs. the other, they will need to use reasoning. For some cards, the reasoning is provided, and for others they need to fill it in.

Implementation Tip

One of the pieces of data students receive is that the Sun releases 2.41 x 10^{30} Mega Electron Volts of energy per second (MeV/s). This is a measure of the Sun's luminosity. Students don't need to know this term yet, but it's very important in the next 5E. The idea of the Sun constantly releasing energy every second can still be introduced. It's unlikely students will be familiar with this, yet, as a measure of luminosity.

Conferring Prompts

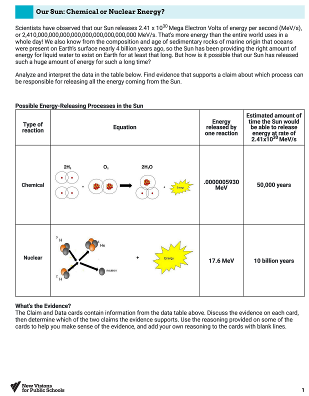
Confer with students as they work in collaborative groups to complete the Claim and Data Cards activity.
Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

- What made you decide this card supports the claim you put it under?
- What makes it relevant to our investigation?
- Is there evidence that can support both claims?
- Which claim seems to have more evidence?
- What reasoning did you add to that card?
- How did the amount of energy produced by the Sun, energy produced by chemical reactions, and energy produced by nuclear fusion help you decide where to place the cards that include that data?

Students may notice that there are some pieces of evidence that do not support *either* of the claims.

Integrating Three Dimensions

This task is an opportunity to start develop an understanding of **CCC #3 - Scale, Proportion, and Quantity** - specifically the idea that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. In this case, students should be able to use the idea of scale as scientific reasoning that links the evidence of how much energy is produced by the Sun, energy produced by chemical reactions, and energy produced by nuclear fusion to the claim that nuclear fusion occurs in the Sun. Energy produced by chemical reactions would not account for the quantity of energy the Sun has produced per second for 5 billion years, whereas energy from nuclear fusion does.



Our Sun: Chemical or Nuclear Energy?

Scientists have observed that our Sun releases 2.41 x 10^{30} Mega Electron Volts of energy per second (MeV/s), or 2,410,000,000,000,000,000,000,000,000,000 MeV/s. That's more energy than the entire world uses in a whole day! We also know from the composition and age of sedimentary rocks of marine origin that oceans were present on Earth's surface nearly 4 billion years ago, so the Sun has been providing the right amount of energy for liquid water to exist on Earth for at least that long. But how is it possible that our Sun has released such a huge amount of energy for such a long time?

Analyze and interpret the data in the table below. Find evidence that supports a claim about which process can be responsible for releasing all the energy coming from the Sun.

Possible Energy-Releasing Processes in the Sun

Type of reaction	Equation	Energy released by one reaction	Estimated amount of time the Sun would be able to release energy at rate of 2.41×10^{30} MeV/s
Chemical	$2H_2$ + O_2 → $2H_2O$ + Energy	.0000005930 MeV	50,000 years
Nuclear	^3H + ^2H → ^4He + neutron + Energy	17.6 MeV	10 billion years

What's the Evidence?
The Claim and Data cards contain information from the data table above. Discuss the evidence on each card, then determine which of the two claims the evidence supports. Use the reasoning provided on some of the cards to help you make sense of the evidence, and add your own reasoning to the cards with blank lines.

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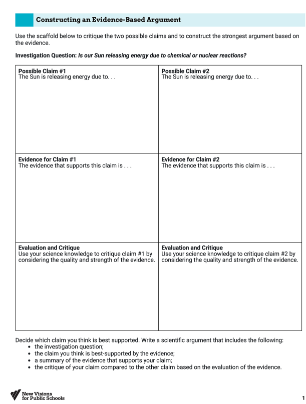
Scientific Explanation for How the Sun Releases Energy

1. Have students use the ideas surfaced from the data card sort and Class Consensus Discussion to develop an explanation for how the Sun releases energy. Students just constructed an explanation in the previous phase. Encourage students to write their explanations without an organizer, as it is likely that less students will need it at this. The organizer should only be provided to students who are clearly still struggling to construct their explanations.

2. See *Constructing an Evidence-Based Argument Student Work* for sample student responses.



Constructing an Evidence-Based Argument

Use the scaffold below to critique the two possible claims and to construct the strongest argument based on the evidence.

Investigation Question: ***Is our Sun releasing energy due to chemical or nuclear reactions?***

Possible Claim #1 The Sun is releasing energy due to. . .	**Possible Claim #2** The Sun is releasing energy due to. . .
Evidence for Claim #1 The evidence that supports this claim is . . .	**Evidence for Claim #2** The evidence that supports this claim is . . .
Evaluation and Critique Use your science knowledge to critique claim #1 by considering the quality and strength of the evidence.	**Evaluation and Critique** Use your science knowledge to critique claim #2 by considering the quality and strength of the evidence.

Decide which claim you think is best supported. Write a scientific argument that includes the following:
- the investigation question;
- the claim you think is best-supported by the evidence;
- a summary of the evidence that supports your claim;
- the critique of your claim compared to the other claim based on the evaluation of the evidence.

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Access for All Learners

Writing a well-reasoned argument is a complex task. By providing time for students to think through the reasoning of their argument (in the card sort), **transitioning** language learners got time to work with the requisite language in preparation for writing. Note that **emerging** English learners may need to do this task with additional support—verbally, in a home language, or some other way.

Implementation Tip

This writing task can be completed in class, or as a take-home task. Students should have what they need from the experience in class to complete this independently.

3. After students complete their arguments, prompt them to reflect on whether they would add anything to their list of criteria for an evidence-based claim.

<u>What Counts as an Evidence-Based Claim?</u>

You found information from a book or a reliable source.

The evidence comes from an experiment or investigation you did.

The claim is not just someone's opinion.

Many scientists can agree on that interpretation.

Patterns in data can count as evidence for a claim. But you have to have evidence for the pattern too.

They can be revised based on new evidence from a different source.

Integrating Three Dimensions

This is a place to continue building on **SEP #6 - Constructing Explanations and Designing Solutions**. Students will probably have new realizations about how to use evidence, what makes evidence strong for supporting a claim, and how looking at new evidence from different sources allows us to revise an explanation.

Classroom Supports

Document any new ideas that come up on the poster *What Counts as an Evidence-Based Claim?*

Evaluate

Developing explanatory and predictive models of the Sun

Students **revise and critique their models** for why Earth has been such an ideal place for life to exist and evolve using **empirical evidence of patterns** in the **Sun's spectra** and lab samples of elemental gases and comparisons of **scale (duration and quantity)** of **energy released by the Sun**. Students **use their model** of our Sun **to predict how the relative proportions of hydrogen to helium changes as the Sun ages** and what that means for the future stages of our Sun.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Small groups of 3-4 students (same groups from Unit Launch)	❑ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❑ What will happen to our Sun in the future? ❑ How the Sun Works Model Rubric ❑ How the Sun Works	None	❑ Driving Question Board ❑ Group's initial models from Unit Launch (chart paper) ❑ *Connect to the Performance Task: How the Sun Works Student Work*

Revise and Share Models

1. Have students revisit the life on Earth time scale from the Anchor Phenomenon and respond to the following questions independently:
   a. How does the amount of time the Sun has been providing the right amount of energy for liquid water to exist on Earth compared to the amount of time it took for life to exist and evolve on Earth? Why is this important?
   b. What do you think would happen to water on Earth if the amount of energy our Sun releases significantly increased or decreased? What effects could this have on humans and other species?

Implementation Tip

The two questions in this Evaluate phase launch are critical to transitioning from this 5E sequence to the next one. This is how you create a "need to know" around what's going to happen to our Sun in the future. If students have already brought up these questions, then they can be rephrased or asked differently.

Routine

This marks the first time **Idea Carousel** appears in this unit. This routine allows for each group to give and receive warm feedback and suggestions around content and clarity in their model, as well as pose and respond to questions. Consult the Unit 1 Teacher Guide for more information on this routine.

2. Ask students to consider their responses to these questions and what they have figured out about how the Sun works, then represent their ideas about why the Sun has been able to support a planet where life has been able to exist and evolve on their initial group models from the performance task launch. These should go onto new pieces of chart paper.

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.

- Our Sun is a star that has provided the Earth with the right amount of energy for liquid water to exist for 5 billion years.
- Over those 5 billion years, life has been sustained on Earth.
- The stability of energy has made Earth a place where humans and other species can survive.
- We can establish the history of Earth using evidence collected by various devices.

3. 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.

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

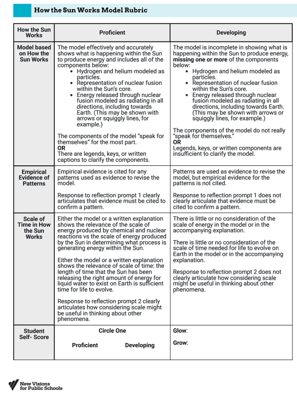
Access for All Learners

The routine **Idea Carousel** is ideal for **emerging language learners**. Students with only receptive language can simply engage by listening and adding annotations.

Return to the Performance Task

1. Using what they learned in the Idea Carousel, have students independently refine their models in their *How the Sun Works*. See the sample response below for an idea of the types of responses to expect at this stage in the unit.

2. After students complete their work, support them to use the *How the Sun Works Model Rubric* for this learning sequence as a self-reflection tool. Here are some ways the rubric can be used:
    a. Have students complete a self-assessment using the rubric.
    b. Create a piece of student work that is a fictional composite of a few different students' work, and complete a critique as a class, while students critique their own work using the rubric.
    c. Collect all the work and score the work, with an eye to how accurate students' self-assessments seem to be.



How the Sun Works Model Rubric

How the Sun Works	Proficient	Developing
Model based on How the Sun Works	The model effectively and accurately shows what is happening within the Sun to produce energy and includes all of the components below: • Hydrogen and helium modeled as particles. • Representation of nuclear fusion within the Sun's core. • Energy released through nuclear fusion modeled as radiating in all directions, including towards Earth. (This may be shown with arrows or squiggly lines, for example.) The components of the model "speak for themselves" for the most part. **OR** There are legends, keys, or written captions to clarify the components.	The model is incomplete in showing what is happening within the Sun to produce energy, **missing one or more** of the components below: • Hydrogen and helium modeled as particles. • Representation of nuclear fusion within the Sun's core. • Energy released through nuclear fusion modeled as radiating in all directions, including towards Earth. (This may be shown with arrows or squiggly lines, for example.) The components of the model do not really "speak for themselves." **OR** Legends, keys, or written components are insufficient to clarify the model.
Empirical Evidence of Patterns	Empirical evidence is cited for any patterns used as evidence to revise the model. Response to reflection prompt 1 clearly articulates that evidence must be cited to confirm a pattern.	Patterns are used as evidence to revise the model, but empirical evidence for the patterns is not cited. Response to reflection prompt 1 does not clearly articulate that evidence must be cited to confirm a pattern.
Scale of Time in How the Sun Works	Either the model or a written explanation shows the relevance of the scale of energy produced by chemical and nuclear reactions vs the scale of energy produced by the Sun in determining what process is generating energy within the Sun. Either the model or a written explanation shows the relevance of scale of time: the length of time that the Sun has been releasing the right amount of energy for liquid water to exist on Earth is sufficient time for life to evolve. Response to reflection prompt 2 clearly articulates how considering scale might be useful in thinking about other phenomena.	There is little or no consideration of the scale of energy in the model or in the accompanying explanation. There is little or no consideration of the scale of time needed for life to evolve on Earth in the model or in the accompanying explanation. Response to reflection prompt 2 does not clearly articulate how considering scale might be useful in thinking about other phenomena.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow:** **Grow:**

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3. Assign students to partnerships and have them review one another's work and self-assessment and provide feedback on the accuracy of the self-assessment.

4. Give each student an opportunity to revise their model using what surfaced from their self-assessment and/or feedback.

Sample Student Response can be found in *Connect to the Performance Task: How the Sun Works Student Work*

Access for All Learners

All students have observed and felt the Sun throughout their lives. The prompts at the end of the rubric are designed to support students in pausing to reflect about why their new ideas are relevant to their lives. After students complete the reflection prompts independently, consider facilitating a whole class share about why learning during this 5E is relevant to students' lives and displaying their responses somewhere in the classroom. This can foster relevance and belonging for all students.

Revisit the Driving Question Board

1. Have students work in pairs and use their understanding of how our Sun works to make predictions in relation to the following three questions:
    a. What do you predict will happen to the amount of hydrogen over time? What evidence do you have for this?
    b. What do you predict will happen to the amount of helium over time? What evidence do you have for this?
    c. Based on what you predicted will happen to the amount of hydrogen and helium over time, what do you think will ultimately happen to the Sun?

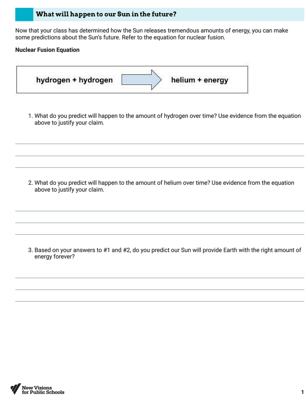
Integrating Three Dimensions

The prompts here are designed to get students to develop further proficiency around **SEP # 2 Developing and Using Models**, specifically using their models to make predictions about phenomena, an important aspect of a high school element of the practice.

Conferring Prompts

There are a few points that might have to be raised as reminders for students to make the connections in these questions. But do not be afraid to allow students to struggle before providing these prompts:

- Examine the equation for nuclear fusion of hydrogen into helium and the composition of one solar mass stars, then answer the questions about our Sun.
- Be sure to consider that fusion of hydrogen into helium is an irreversible reaction in the Sun; helium will not break apart to reform hydrogen again.



What will happen to our Sun in the future?

Now that your class has determined how the Sun releases tremendous amounts of energy, you can make some predictions about the Sun's future. Refer to the equation for nuclear fusion.

Nuclear Fusion Equation

hydrogen + hydrogen → helium + energy

1. What do you predict will happen to the amount of hydrogen over time? Use evidence from the equation above to justify your claim.
2. What do you predict will happen to the amount of helium over time? Use evidence from the equation above to justify your claim.
3. Based on your answers to #1 and #2, do you predict our Sun will provide Earth with the right amount of energy forever?

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Look & Listen For

While pairs are sharing their responses, listen for these ideas, to provide a bridge to the next 5E:

- The amount of hydrogen will go down because two hydrogen are fusing to create helium and release energy.
- The amount of helium will increase because it is being created by fusion of two hydrogens.
- The sun will eventually run out of hydrogen and not release any more energy.
- The Sun will explode
- Maybe the helium will fuse and create heavier elements and release more energy.

2. Revisit the Driving Question Board questions and have students identify what they have figured out and what they still need to investigate. Use the Group Learning Routine **Domino Discover** to hear different pairs' ideas. Prompt students to generate new questions related to finding another star that can potentially support an Earth-like planet.

Anticipated questions:

- When will other stars run out of fuel and stop producing energy?
- Will other stars provide the right amount of energy for liquid water to exist on a planet that revolves around them?
- Will other stars allow liquid water to exist long enough for life to exist and evolve?

- Will other stars provide the right amount of energy for humans and other species to survive a long time?

3. Use questions like the ones above or any other questions related to planet characteristics and whether they have liquid water to transition to the next 5E investigation. Say “I’m noticing a lot of questions related to planet characteristics and whether they have liquid water, so tomorrow I will have some resources available for the class to investigate these questions.”

Standards in How the Sun Works 5E

Performance Expectations

HS-ESS1-1 **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.**
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.
Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.

In NYS, all occurances of the term "sun" in this PE have been formatted as "Sun."

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3) 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.A The Universe and Its Stars • The star called the Sun is changing and will burn out over a life span of approximately 10 billion years. ESS1.A(1) • 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) PS3.D Energy in Chemical Processes and Everyday Life • Nuclear fusion processes in the center of the Sun release the energy that ultimately reaches Earth as radiation. PS3.D(1) PS4.B Electromagnetic Radiation • Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. PS4.B(4)	Patterns • Empirical evidence is needed to identify patterns. CCC1(5) Scale, Proportion, and Quantity • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. CCC3(1)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Developing and Using Models					Revised Performance Task models
Constructing Explanations and Designing Solutions	Initial ideas about Sun and related observations	See-Think-Wonder	CER for Sun's composition	Scaffolded Explanation Task (Card Sort)	
ESS1.A The Universe and Its Stars	Rumors	See-Think-Wonder	CER for Sun's composition	Scaffolded Explanation Task (Card Sort)	Predictions about Sun
PS3.D Energy in Chemical Processes and Everyday Life	Rumors			Scaffolded Explanation Task (Card Sort)	
PS4.B Electromagnetic Radiation		See-Think-Wonder	CER for Sun's composition		
Patterns		See-Think-Wonder	CER for Sun's composition		Revised Performance Task models
Scale, Proportion, and Quantity				Scaffolded Explanation Task (Card Sort)	Revised Performance Task models

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		MP2	MP2	MP2	MP2
ELA/Literacy		RST.9-10.7 WHST.9-10.9 SL.9-10.5	RST.9-10.7 WHST.9-10.1 SL.9-10.4	RST.9-10.1 WHST.9-10.1 WHST.9-10.9 SL.9-10.4	WHST.9-10.1 WHST.9-10.9 SL.9-10.4 SL.9-10.5

Student Work for How the Sun Works 5E

Investigating Light from the Sun Student Work

Part 1: What does a spectrometer tell us about light?

4. Explain your observations: what do you think happened to the light from the lightbulb as it passed through the gas cloud before passing through the spectroscopy telescope?

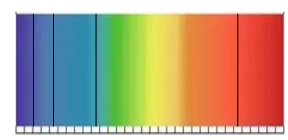
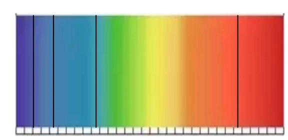
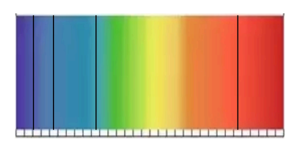
- The stuff in the dust cloud blocked some of the light. That's why you see black lines.
- No matter where the light comes from, the colors in the spectrum are in the same order.
- when the light from the bulb passed through the dust cloud, it was interrupted, so it looks like that with black lines.
- Something is blocking parts of the light so we don't see the whole rainbow.
- Some of the light looks like it got trapped in the dust cloud.

Part 2: What do we see when we observe the Sun with a spectrometer?

The Sun is made of gases. Just like in the simulation, light released from inside the Sun has to pass through the gases that make up the Sun. In this part of the investigation you will determine the pattern in the light from the Sun.

Astronomers used a spectroscopy telescope to collect data while observing the Sun on several occasions. Using the table below, answer questions about the Sun.

Spectra from the Sun

Observation	Spectrum
1	
2	
3	

1. What pattern do you notice in the sunlight data across the 3 observations? Describe the *evidence* for the pattern.

They are all the same. The black lines line up in the same places in all three observations.

The pattern in the black lines is identical in observations 1, 2, and 3. The evidence is that you can look at the numbers under the black lines and see they are the same.

2. What do you think *caused* the pattern you observe?

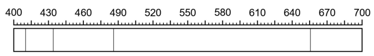
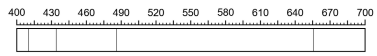
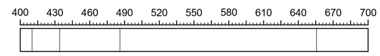
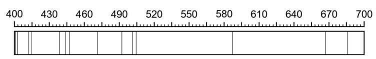
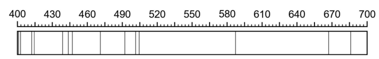
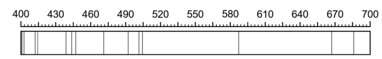
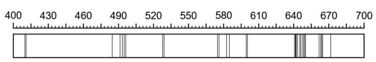
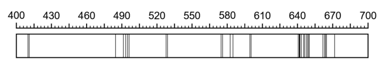
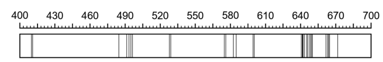
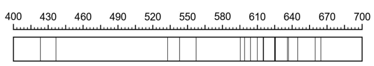
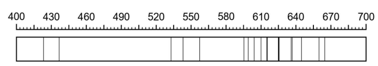
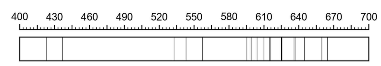
The light from the Sun isn't changing; no matter how many times you observe it, the spectrum will always look the same.

whatever the Sun is made of is blocking parts of certain colors, just like in the simulation.

Part 3: How does the Sun's spectrum compare to the spectra from light passed through gases in a lab?

The spectra data below were collected in a laboratory when light was passed through several samples of each isolated gases listed. We can compare these spectra from the lab to the Sun's spectrum to figure out which gas(es) the Sun is composed of.

Spectra of Elements Observed in a Lab

Gas	Sample 1	Sample 2	Sample 3
Hydrogen			
Helium			
Nitrogen			
Oxygen			

See-Think-Wonder

Directions: Refer to the table of spectra above to complete the organizer.

See What pattern did you observe in the data?	Think What could this pattern mean?	Wonder What questions do you have about this pattern?

- The stuff in the dust cloud blocked some of the light. That's why you see black lines.
- No matter where the light comes from, the colors in the spectrum are in the same order.
- when the light from the bulb passed through the dust cloud, it was interrupted, so it looks like that with black lines.
- Something is blocking parts of the light so we don't see the whole rainbow.
- Some of the light looks like it got trapped in the dust cloud.

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- Some of the light looks like it got trapped in the dust cloud.

Connect to the Performance Task: How the Sun Works Student Work

What makes Earth habitable?

After discussing how you would change your initial model with your group based on what you figured out about how the Sun works, record your revised model for what makes Earth habitable. Be sure to represent your understanding of how the Sun is able to release the right amount of heat and energy for the right amount of time to support the existence of life on Earth. Consider and respond to the following reflection prompts before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. What is the **evidence for the patterns** you identified?

The black absorption lines always appear above the same wavelength number for the Sun and each element gas respectively.

2. How will those **patterns** change your model?

The pattern in the Sun's spectra matches the pattern in the spectra of hydrogen and helium gas, so we know the Sun is composed of hydrogen and helium gas and will represent that in our model.

3. How did you use the **scale of energy and time** to figure out how the Sun works?

we noticed that the scale of energy released by the Sun cannot be accounted for by the scale of energy released by chemical reactions involving hydrogen and that the scale of energy produced by nuclear fusion of hydrogen can account for the energy released by the Sun, so we think that hydrogen fusion is occuring in the Sun and is the process that causes it to release energy.

4. How do you think considering **scale** might be useful in thinking about other phenomena?

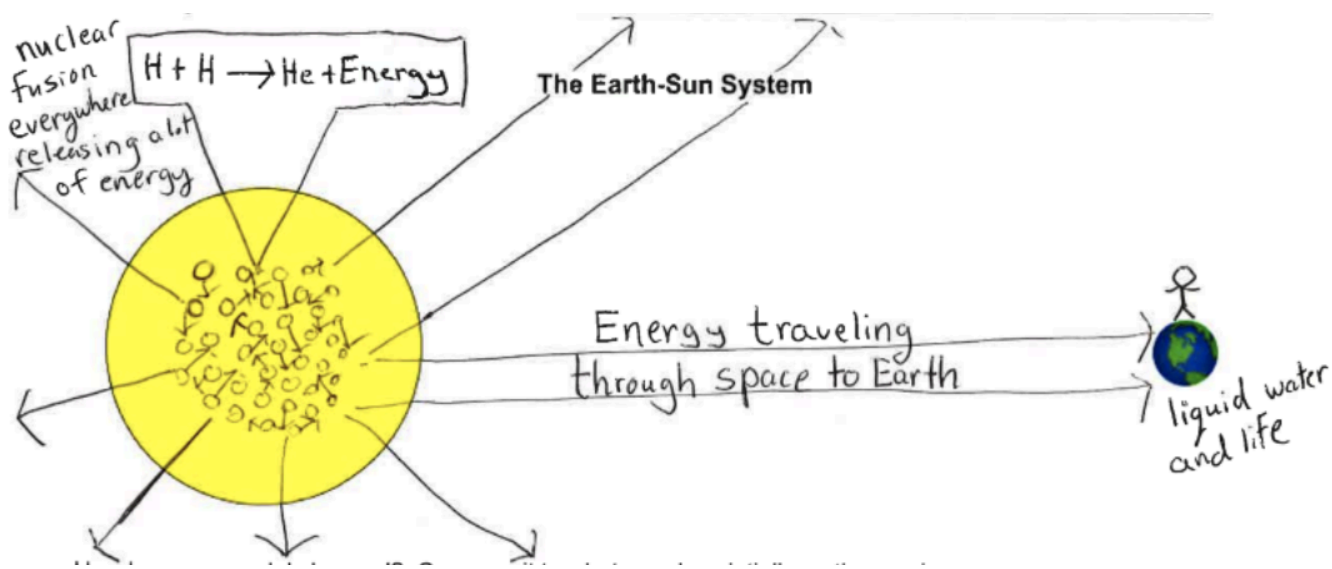
we think that when we investigate other phenomena, scale might be useful for knowing which possible processes to consider and which we can rule out as explanations for what we observe of the phenomena.

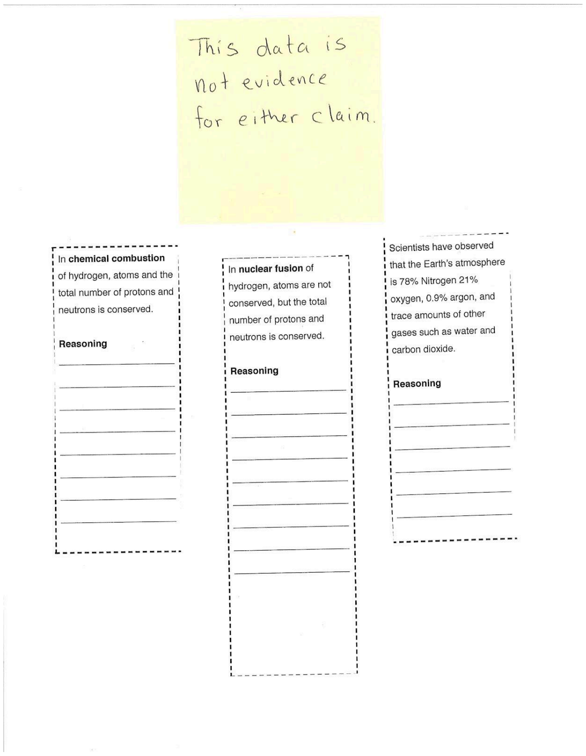
Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your initial model for why Earth is a planet that can sustain life.

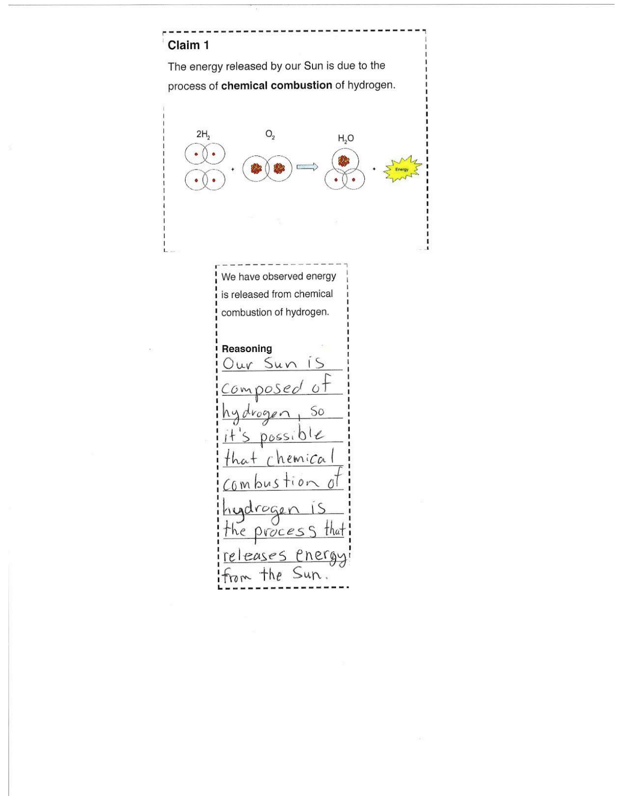
Change to the Model	Evidence	Scientific Reasoning
Representing the Sun's composition as hydrogen and helium.	The pattern in the Sun's spectra matches the pattern in the spectra of hydrogen and helium gas	Each element has a unique absorption spectra.
Representing nuclear fusion of hydrogen as the process occuring in the Sun that causes it to release tremendous amounts of energy.	The Sun is composed of hydrogen and helium. Chemical reactions of hydrogen burning involve oxygen and produce water, we did not see evidence of weather in the Sun's spectra. Chemical reactions that occur when hydrogen is burned release very little energy while nuclear fusion of hydrogen produces a huge amount of energy.	The scale of energy released by the Sun cannot be accounted for by the scale of energy released by chemical reactions involving hydrogen and that the scale of energy produced by nuclear fusion of hydrogen can account for the energy released by the Sun.

2. In the space below, draw a revised version of your initial model for why Earth is a planet that can sustain life below.

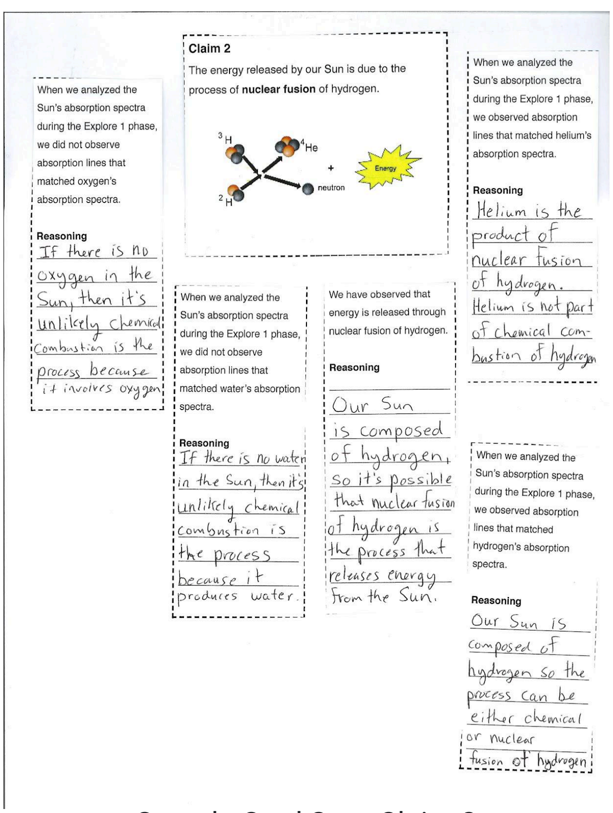




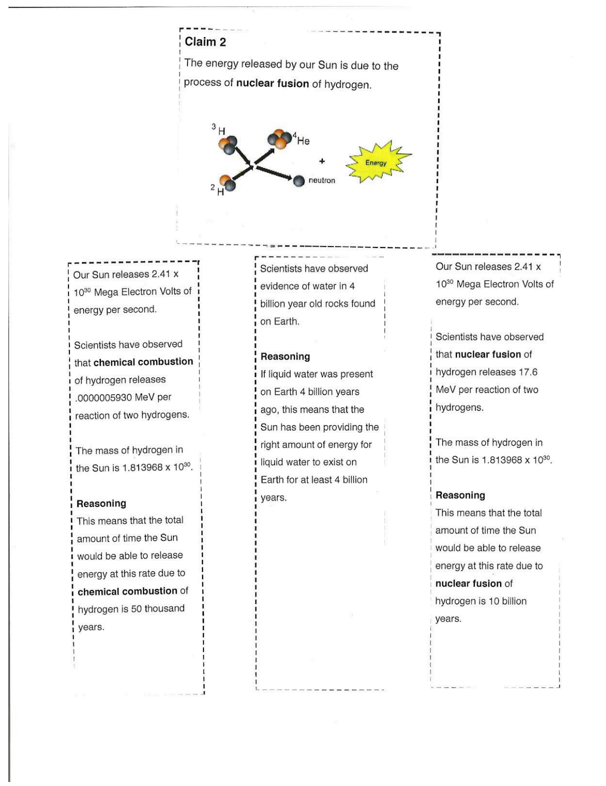
Sample Card Sort: Evidence not Connected to a Claim



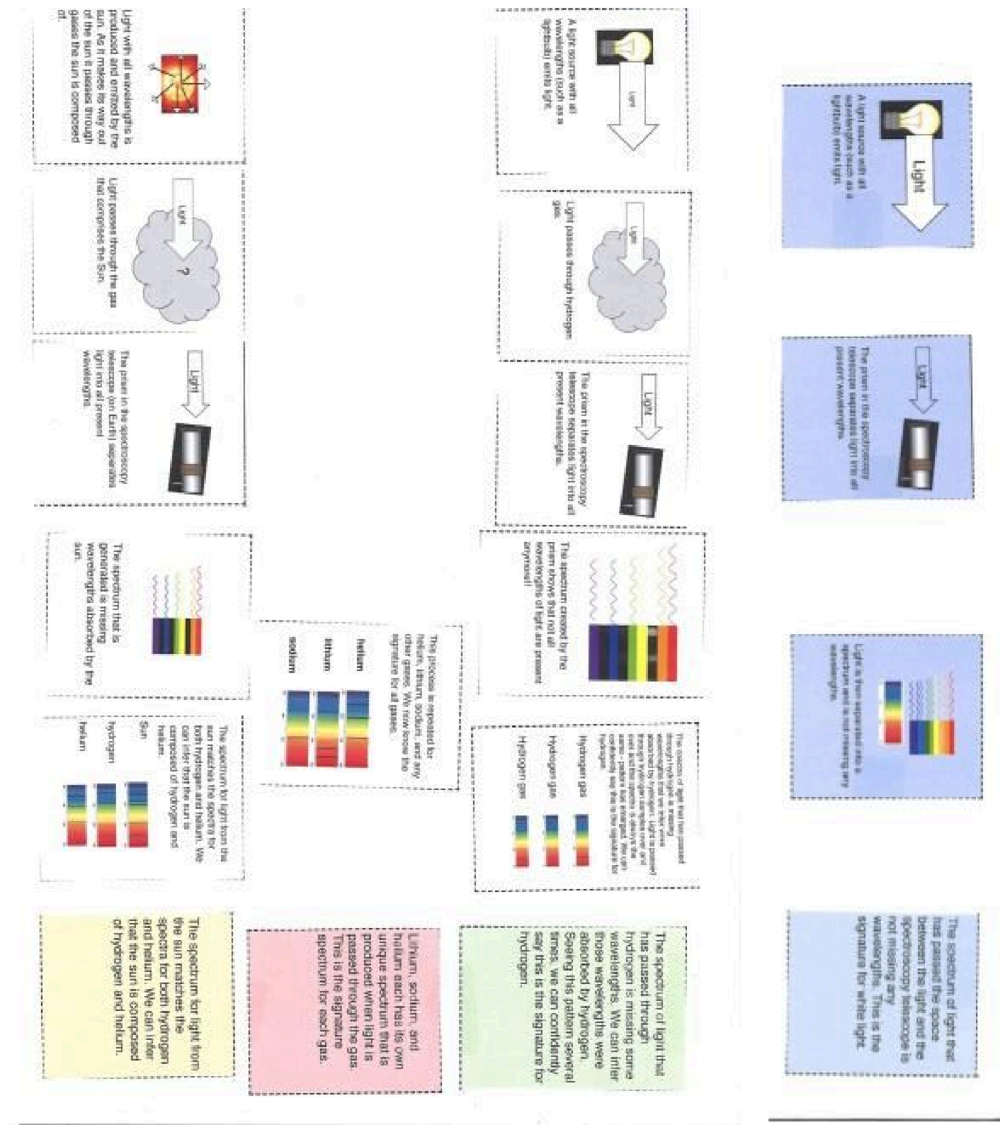
Sample Card Sort: Claim 1



Sample Card Sort: Claim 2



Spectra Sequence Chart Student Work



Determining the Composition of the Sun Student Work

What is the composition of the Sun? How do you know?

Make a scientific claim about which gas or gases the Sun is composed of based on your data from the Explore phase and your understanding of how light behaves when it passes through gases.

Our Sun is composed of hydrogen and helium. My evidence for this is that the light spectrum for the Sun has the same absorption wavelengths as the light spectra for hydrogen and helium. Absorption lines in the spectrum for any given gas will always be the same. This means if the Sun has a light spectrum with the same absorption wavelengths as the light spectra for Hydrogen and helium, the light from the Sun must have passed through hydrogen and helium as it exited the Sun's outer layers.

Constructing an Evidence-Based Argument Student Work

Use the scaffold below to critique the two possible claims and to construct the strongest argument based on the evidence.

Investigation Question: ***Is our Sun releasing energy due to chemical or nuclear reactions?***

Possible Claim #1 The Sun is releasing energy due to. . . Chemical reactions	**Possible Claim #2** The Sun is releasing energy due to. . . Nuclear reactions
Evidence for Claim #1 The evidence that supports this claim is . . . There are different reactants and products, which means there is a chemical reaction.	**Evidence for Claim #2** The evidence that supports this claim is . . . The Sun has been around way longer than it would have been if it was having a chemical reaction.
Evaluation and Critique Use your science knowledge to critique claim #1 by considering the quality and strength of the evidence. The fact that there are reactants and products isn't enough evidence. The same is true of nuclear reactions!	**Evaluation and Critique** Use your science knowledge to critique claim #2 by considering the quality and strength of the evidence. This is a stronger piece of evidence, but since the Sun is so large, maybe it's scale is great enough to keep a non-nuclear reaction going for a long time.

Decide which claim you think is best supported. Write a scientific argument that includes the following:

- the investigation question;
- the claim you think is best-supported by the evidence;
- a summary of the evidence that supports your claim;
- the critique of your claim compared to the other claim based on the evaluation of the evidence.

we have been investigating the following question: how does the Sun release so much energy? My claim is that the Sun releases energy through nuclear fusion. One piece of evidence is that there is hydrogen and helium in the Sun. when hydrogen undergoes fusion it turns into helium. Another piece of evidence is that there is a lot of energy being released, over a long time. This happens in nuclear fusion. One critique of my claim could be that the Sun is very large, so perhaps it is just undergoing chemical reactions for a very long time.

Classroom Resources for How the Sun Works 5E

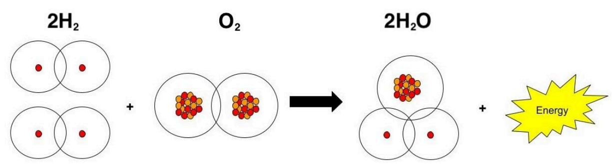
Claim and Data Cards
Spectra Sequence Chart
What Counts as an Evidence-Based Claim?

Claim and Data Cards

Cut out these cards.

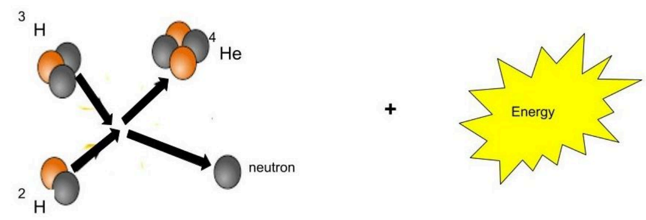
Claim 1

The energy released by our Sun is due to the process of **chemical combustion** of hydrogen.



Claim 2

The energy released by our Sun is due to the process of **nuclear fusion** of hydrogen.



Our Sun releases 2.41 x 10^{30} Mega Electron Volts of energy per second.

Scientists have observed that **chemical combustion** of hydrogen releases .0000005930 MeV per reaction of two hydrogens.

The mass of hydrogen in the Sun is 1.813968 x 10^{30}.

Reasoning

This means that the total amount of time the Sun would be able to release energy at this rate due to **chemical combustion** of hydrogen is 50 thousand years.

Our Sun releases 2.41 x 10^{30} Mega Electron Volts of energy per second.

Scientists have observed that **nuclear fusion** of hydrogen releases 17.6 MeV per reaction of two hydrogens.

The mass of hydrogen in the Sun is 1.813968 x 10^{30}.

Reasoning

This means that the total amount of time the Sun would be able to release energy at this rate due to **nuclear fusion** of hydrogen is 10 billion years.

Scientists have observed evidence of water in 4 billion year old rocks found on Earth.

Reasoning

If liquid water was present on Earth 4 billion years ago, this means that the Sun has been providing the right amount of energy for liquid water to exist on Earth for at least 4 billion years.

In **nuclear fusion** of hydrogen, atoms are not conserved, but the total number of protons and neutrons is conserved.

Reasoning

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When we analyzed the Sun's absorption spectra during the Explore 1 phase, we did not observe absorption lines that matched oxygen's absorption spectra.

Reasoning

When we analyzed the Sun's absorption spectra during the Explore 1 phase, we observed absorption lines that matched helium's absorption spectra.

Reasoning

When we analyzed the Sun's absorption spectra during the Explore 1 phase, we did not observe absorption lines that matched water's absorption spectra.

Reasoning

We have observed that energy is released through nuclear fusion of hydrogen.

Reasoning

We have observed energy is released from chemical combustion of hydrogen.

Reasoning

When we analyzed the Sun's absorption spectra during the Explore 1 phase, we observed absorption lines that matched hydrogen's absorption spectra.

Reasoning

Scientists have observed that the Earth's atmosphere is 78% Nitrogen 21% oxygen, 0.9% argon, and trace amounts of other gases such as water and carbon dioxide.

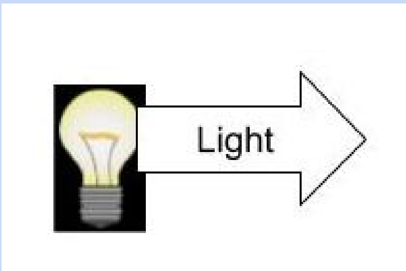
Reasoning

In **chemical combustion** of hydrogen, atoms and the total number of protons and neutrons is conserved.

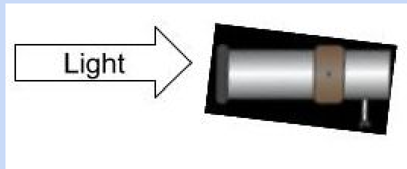
Reasoning

Spectra Sequence Chart

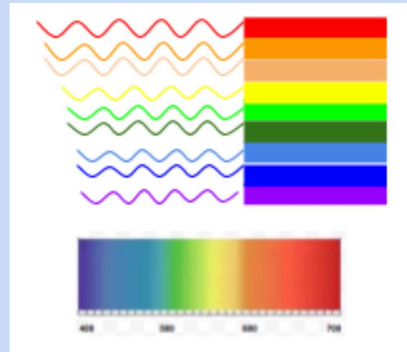
Cut out these cards.



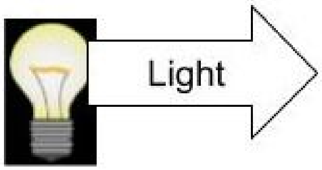
A light source with all wavelengths (such as a lightbulb) emits light.



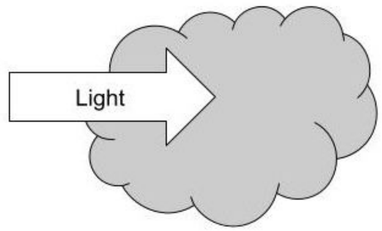
The prism in the spectroscopy telescope separates light into all present wavelengths.



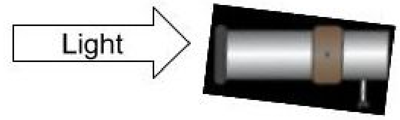
Light is then separated into a spectrum and is not missing any wavelengths.



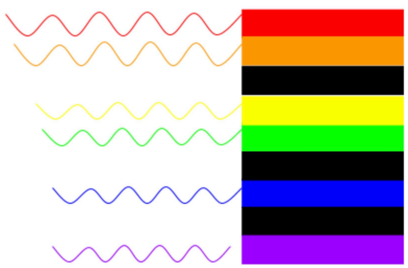
A light source with all wavelengths (such as a lightbulb) emits light.



Light passes through hydrogen gas.



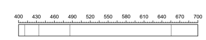
The prism in the spectroscopy telescope separates light into all present wavelengths.

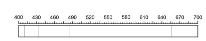


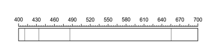
The spectrum created by the prism shows that not all wavelengths of light are present anymore!!

The spectrum of light that has passed through hydrogen is missing some wavelengths. We can infer those wavelengths were absorbed by hydrogen. Seeing this pattern several times, we can confidently say this is the signature for hydrogen.

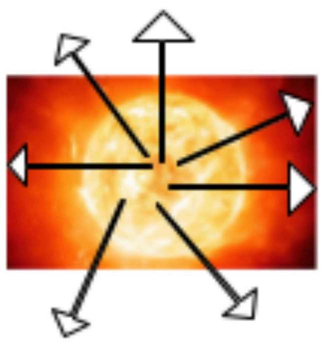
The spectrum of light that has passed through hydrogen is missing wavelengths that we infer were absorbed by hydrogen. Light is passed through hydrogen samples over and over and the spectrum is always the same - pattern has emerged. We can confidently say this is the signature for hydrogen.

Hydrogen gas 

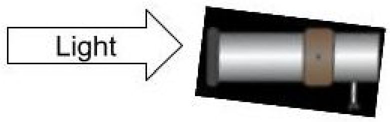
Hydrogen gas 

Hydrogen gas 

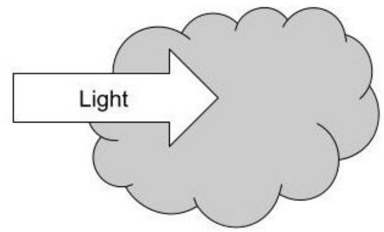
Use this master to create cards for the card sequence activity.



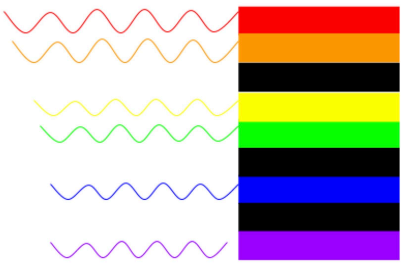
Light with all wavelengths is produced and emitted by the sun. As it makes its way out of the sun it passes through gases the sun is composed of.



The prism in the spectroscopy telescope (on Earth) separates light into all present wavelengths.



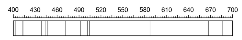
Light passes through the gas that comprises the Sun.



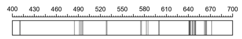
The spectrum that is generated is missing wavelengths absorbed by the sun.

This process is repeated for helium, nitrogen, oxygen, and any other gases. We now know the signature for all gases.

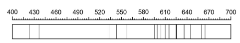
helium



nitrogen

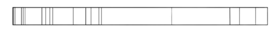


oxygen

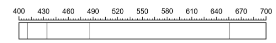


The spectrum for light from the sun matches the spectra for both hydrogen and helium. We can infer that the sun is composed of hydrogen and helium.

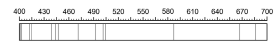
Sun



hydrogen



helium



Nitrogen, oxygen, and helium each has its own unique spectrum that is produced when light is passed through the gas. This is the signature spectrum for each gas.

The spectrum of light that has passed the space between the light and the spectroscopy telescope is not missing any wavelengths. This is the signature for white light.

The spectrum for light from the sun matches the spectra for both hydrogen and helium. We can infer that the sun is composed of hydrogen and helium.

What Counts as an Evidence-Based Claim?

What Counts as an Evidence-Based Claim?

You found information from a book or a reliable source.

The evidence comes from an experiment or investigation you did.

The claim is not just someone's opinion.

Many scientists can agree on that interpretation.

Patterns in data can serve as evidence.

Star Life Cycles 5E	Does the exoplanet have a star like our Sun? What is our Sun like, compared to other stars?	**Performance Expectations** HS-ESS1-1, HS-ESS1-3	**Investigative Phenomenon** Historical records from all over the world describe the explosion of a star in 1054.	**Time** 7 days

What are we trying to figure out? In this 5E instructional sequence, students are continuing to investigate the question surfaced during the Driving Question Board launch - Does the exoplanet have a Sun like ours? Through the How the Sun Works 5E, students learned that the Sun is a star that has been providing Earth with the right amount of energy for liquid water to exist on Earth for about 4 billion years, making it possible for Earth to sustain life. In this 5E, students shift from investigating stars on a solar system scale to studying stars on a galactic scale in order to make further sense of why our Sun has been able to provide Earth with the right amount of energy for such a long time. Students discover that not all stars are as stable as our Sun which leads to the need to develop a model that explains why the Sun is so stable and why other stars change more rapidly. Finally, students investigate which properties of stars are observable, what those properties tell us about the time frame for a star's energy production, and how this relates to the stability of their rate of energy release. Students then argue from evidence about which star in the performance task data set is most likely to support a planet that can sustain life.

ENGAGE	What happens to stars over time? What will happen to our Sun in the future?	Students **observe a data visualization** of a **supernova** and share their initial ideas about what caused the star to **change** and **explode**. Students then **generate questions** related to the **stability** of a star that is likely to support an Earth-like planet.
EXPLORE 1	Observing patterns of star stability and change over time	Students **use a computational model** of **star life cycles** to **look for evidence of patterns** in the relationship between **star mass** and **stability and change** in stars, so that they can identify stars with the longest and most stable lifespans.
EXPLORE 2	Making connections between observable star properties and lifespan	Students **develop and analyze a mathematical model** (the Hertzsprung-Russell Diagram) to look for **evidence of patterns** in the relationships between **observable star properties and lifespan**.
EXPLAIN	Developing an explanatory model for patterns of stability and change observed in stars	Students use their understanding of **nucleosynthesis and gravity in stars** to **develop an explanatory model** for **stability and change** in **star life cycles** observed during the Explore phases.
ELABORATE	Using a model of nucleosynthesis in stars in order to explain differences in stability and change in stars	Students collect data from a **computational model of nucleosynthesis in stars** in order to **identify patterns** in the relationship between **mass of a star** and **nucleosynthesis**. They **use these patterns** to **explain why stability varies** across stars of different mass, and why **higher mass stars are able to produce heavier elements**.
EVALUATE	Constructing arguments for which star is most likely to support a planet that can sustain life	Students **critique and revise their models** for why Earth has been an ideal planet for sustaining life **using evidence** about star **stability**. They **use evidence** about how and why **our Sun and other stars change or remain stable over time** to **argue** about which star in the performance task data set is most likely to support an Earth-like planet.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

What happens to stars over time? What will happen to our Sun in the future?

Students **observe a data visualization** of a **supernova** and share their initial ideas about what caused the star to **change** and **explode**. Students then **generate questions** related to the **stability** of a star that is likely to support an Earth-like planet.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ What Was Supernova 1054? ❏ Text: What Was Supernova 1054?	None	❏ Supernova 1054 - Crab Nebula remnant

Launch

1. Remind students that, during the Evaluate phase of the previous 5E, they concluded that one of the reasons Earth has been able to sustain life is that our Sun has provided Earth with the right amount of energy for liquid water to exist for over 4 billion years. After the previous 5E instructional sequence on How the Sun Works, a category of questions that emerged was about the future of *other* stars (for example: *Will other stars burn out soon after we get to a planet that revolves around it? Will other stars produce the right amount of energy for liquid water to exist long enough for life to evolve?*)

2. Tell students that while we cannot know for sure what will happen to our Sun and other stars, humans have made some observations of stars that can provide clues about our Sun and other stars.

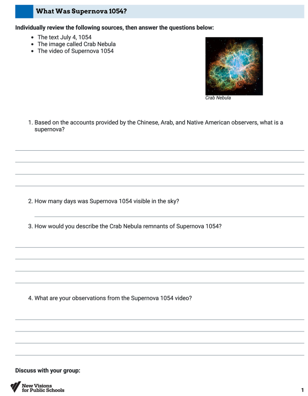
3. Have students review the text *Text: What Was Supernova 1054?*, image, and video about Supernova 1054 and its aftermath. Students should answer questions 1-4 on *What Was Supernova 1054?* individually, then discuss the story of Supernova 1054 with their groups.

4. Invite students to share out the story of Supernova 1054 using a **Domino Discover.** There would not be a great deal of difference among groups; the purpose is to make sure everyone understands what the phenomenon is. If the following points do not come up, it is worth bringing them up:
   a. Supernova 1054 event was about 654 days according to historical accounts.
   b. Scientists have used those accounts and other observations of supernovas to create a data visualization of Supernova 1054.
   c. Supernova 1054 turned into a crab nebula, which is still visible.

Access for All Learners

By providing text, video, and images, the teacher can support all students' engagement with the investigative phenomenon. The visual resources will be particularly helpful to **below level readers**. Some students may struggle with the idea that the supernova was visible a long time ago (1054), but its remnants are still visible. Telling the story with their group helps with this.

5. Have students turn to a partner and discuss the following prompt about relevant phenomena: *What other phenomena are you familiar with that are similar to the Supernova 1054 phenomenon?*



What Was Supernova 1054?

Individually review the following sources, then answer the questions below:

- The text July 4, 1054
- The image called Crab Nebula
- The video of Supernova 1054

Crab Nebula

1. Based on the accounts provided by the Chinese, Arab, and Native American observers, what is a supernova?
2. How many days was Supernova 1054 visible in the sky?
3. How would you describe the Crab Nebula remnants of Supernova 1054?
4. What are your observations from the Supernova 1054 video?

Discuss with your group:

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Access for All Learners

While all students have some background knowledge on stars, it's likely that most of them have never thought about how stars change since we cannot observe change in stars on the scale of a human lifetime. Asking students to think about a similar phenomena they are familiar with will help them connect to ideas about stability and change they already know. This will help all students generate initial questions about how stars change.

Look & Listen For

Listen for the following ideas that students likely learned in middle school or will draw from what they learned during the How the Sun Works investigation:

- Nuclear explosions
- When the solar system formed from a disk of dust and gas that was drawn together by gravity (MS.ESS1.B)

6. Remind students that they are looking for a star that lives long enough and provides stable enough conditions for water to exist in liquid form, sustaining life on its planets. Have students independently jot their initial ideas about why a star explodes in question 5 on the handout.

Discuss with your group:

1. What is the overall story about Supernova 1054?

In the beginning. . .	Then. . .	Now. . .

5. What are your initial ideas about what caused the changes in the star that you just observed in the visualization?

Surfacing Student Questions

1. Prompt students to work in pairs to generate questions that can frame the investigation of stars that could support an Earth-like planet. Here is a possible way to frame this prompt: "We know from Supernova 1054 that stars do not last forever. What do we need to know about the life and death of stars? Keep in mind that we are trying to figure out more about a star that could support an Earth-like planet"

2. Use the Group Learning Routine **Domino Discover** to surface and document the range of student questions in the class.

3. Students are likely to have a range of questions. Have students discuss with a partner which three questions surfaced by the class are most relevant to finding a star that might be able to support an Earth-like planet.

Look & Listen For

In middle school students learned that looking for patterns in data can help determine cause and effect relationships and that explanations of stability and change can be constructed by examining changes over time. They also learned about the role of gravity in the solar system formation from a disk of dust, which looks similar to the crab nebula, While pairs are sharing their responses, listen for these ideas:
Anticipated Student questions:

- Will our Sun change and explode? When?
- Would a star that explodes like that destroy planets around it?
- What causes a star to change and explode? (CCC #1 MS)
- How do different stars change over time? Are there patterns? (CCC #7 MS)
- Are there patterns in the way stars change? (CCC #1 MS)
- Are nuclear reactions the cause? (CCC #7 MS)
- Are changes in stars fast or slow? (CCC #7 MS)
- Does gravity have anything to do with stars changing and exploding? (MS.ESS1.B)
- If our Sun explodes, will it destroy Earth and other planets?
- Will other stars change and explode?

4. Tell students that the class will need to investigate further in order to answer the questions they've generated and make a determination about which stars in the performance task data set are most likely to support an Earth-like planet.

Routine

The routine **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 Unit 1 Teacher Guide for support with this routine.

Access for Multilingual Learners

In this **Domino Discover,** it is likely that many of the same ideas will surface from multiple groups. That's intentional! Students who are **emerging language learners** benefit from a few additional rounds of comprehensible input, from different speakers.

Integrating Three Dimensions

The kinds of questions students might ask at this point are probably going to relate to the **CCC #7 - Stability and Change.**

Classroom Supports

Create a poster or space on a whiteboard for categories of student questions about stars that have come up. Use the title *What do we need to know about other stars?*

Explore 1

Observing patterns of star stability and change over time

Students **use a computational model** of **star life cycles** to **look for evidence of patterns** in the relationship between **star mass** and **stability and change** in stars, so that they can identify stars with the longest and most stable lifespans.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ What Properties of Stars Give Us Clues About Their Life Spans? ❑ What Kinds of Stars Have Long and Stable Life Spans?	None	❑ *What Kinds of Stars Have Long and Stable Life Spans? Student Work* ❑ Star in a Box Simulation

Launch

1. Ask students about the data from other stars that would provide evidence to help them answer the questions they generated during the Engage phase and any other questions about stars previously generated.

Implementation Tip

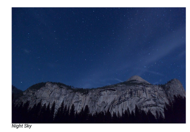
One major shift in the *K-12 Framework* is towards the privileging of student sensemaking. Ask students to think about the data they want to collect as a way to support their engagement in the sensemaking process. If students are having trouble thinking about what data they want, prompt them to think about the Sun data they examined in the How the Sun Works 5E.

Look & Listen For

Students may generate ideas such as:

- Light from other stars
- Spectra data from other stars
- Brightness of other stars
- How long stars live
- Temperature of stars
- How much the temperature of other stars change
- How much energy other stars release and for how long

2. Prompt students to answer the questions on the *What Properties of Stars Give Us Clues About Their Life Spans?* handout individually, then discuss with a partner. The purpose of this prompt is to get students to notice that, from Earth, we mostly see stars as little white dots of light. This is different from the view from a space telescope (like Hubble) which they will see in a moment. Ask some of the pairs to share out their observations and thoughts about what they might see if they viewed the same stars through an even more powerful telescope that's in space.



What Properties of Stars Give Us Clues About Their Life Spans?

Have you ever seen stars in the night sky? If you live in the city, you may see fewer stars than in the image below. From a dark place on Earth, many stars are visible.

Night Sky

1. What do you think we would see if we looked at that same portion of the sky with an even more powerful telescope?

2. What do you think we would see if we looked at the stars with a telescope that is in space?

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Implementation Tip

The night sky image can also just be projected onto a screen for students to discuss, if getting a decent copy of the image for all students is a challenge.

Hubble Star Data

1. Have students read the paragraph about the Hubble telescope and look at the Hubble telescope image of a star cluster. Point out that the powerful Hubble telescope allows us to see much more detail about

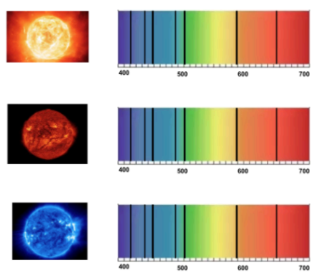
the light produced by stars. Focus on the Hubble star cluster image and the sample star spectra data from the cluster as they respond to the questions.

Look & Listen For

Students may generate ideas such as:

- The stars are different colors
- The stars are different sizes
- The stars vary in brightness
- The stars are different shapes and we see much more detail
- The sample spectra of stars indicates they are made of hydrogen and helium just like our Sun
- The difference in color is caused by temperature
- The difference in size has to do with distance
- The difference in brightness has to do with distance

Spectra Data from Omega Centauri Star Cluster



2. What do you observe in the star light spectra from stars in the Hubble image? Explain your observations.

3. What do you think explains the differences observed in the stars, given your observations about the spectra?

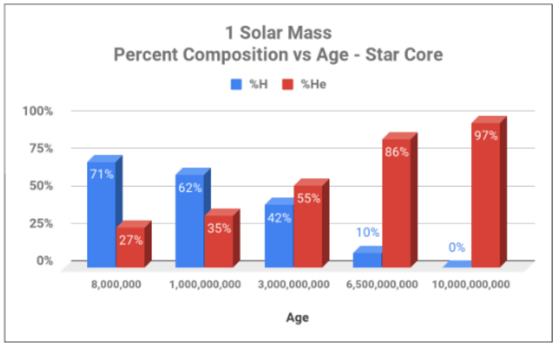
2. Have several students share their responses to each question. Document student ideas as they share out. After composition and variation in size have surfaced, ask the class what they think that means in terms of the amount of hydrogen fuel they have and mass.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following **key points**, which can be documented with the other points that come up:

- Larger stars made of the same stuff will have more of that stuff (hydrogen and helium.)
- Larger stars therefore have more mass.

Composition of 1 Solar Mass Star



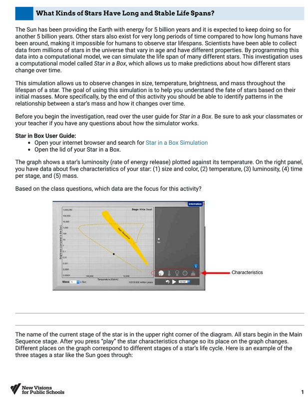
3. Display or provide a handout of the hydrogen/helium ratio data of one solar mass stars. This is the data students analyzed and interpreted in the Elaborate phase of the How the Sun Works 5E. Highlight the fact that the data showed the Sun would run out of hydrogen fuel after a life span of 10 billion years. Ask students what they think we should consider about stars if we want to determine how long their life spans are. Students may bring up the amount of hydrogen, or the mass of the star.

4. Transition into the investigation on the next Explore 1 handout, *What Kinds of Stars Have Long and Stable Life Spans?*, where they will be using a computational model that allows them to observe predicted life spans and changes in stars of different masses (or amount of hydrogen).

Planning to Work with a Computational Model

1. Have students read the text about why and how the computational model Star in a Box was developed and the user guide for it. Be sure that students have an opportunity to explore the functionality of Star in the Box and raise any questions they have about using the model. Incorporating time for them to "play around" with the tool before using it to make sense of data ensures that they are not just following steps in this Explore phase!

2. Ask students to identify which data, based on the earlier discussion, should be the focus of this investigation. Since there are many pieces of data available in this model that are not related to the investigation, it is important to check that students understand what they should focus on.



What Kinds of Stars Have Long and Stable Life Spans?

The Sun has been providing the Earth with energy for 5 billion years and it is expected to keep doing so for another 5 billion years. Other stars also exist for very long periods of time compared to how long humans have been around, making it impossible for humans to observe star lifespans. Scientists have been able to collect data from millions of stars in the universe that vary in age and have different properties. By programming this data into a computational model, we can simulate the life span of many different stars. This investigation uses a computational model called *Star in a Box*, which allows us to make predictions about how different stars change over time.

This simulation allows us to observe changes in size, temperature, brightness, and mass throughout the lifespan of a star. The goal of using this simulation is to help you understand the fate of stars based on their initial masses. More specifically, by the end of this activity you should be able to identify patterns in the relationship between a star's mass and how it changes over time.

Before you begin the investigation, read over the user guide for *Star in a Box*. Be sure to ask your classmates or your teacher if you have any questions about how the simulator works.

Star in Box User Guide:
- Open your internet browser and search for Star in a Box Simulation
- Open the lid of your Star in a Box.

The graph shows a star's luminosity (rate of energy release) plotted against its temperature. On the right panel, you have data about five characteristics of your star: (1) size and color, (2) temperature, (3) luminosity, (4) time per stage, and (5) mass.

Based on the class questions, which data are the focus for this activity?

The name of the current stage of the star is in the upper right corner of the diagram. All stars begin in the Main Sequence stage. After you press "play" the star characteristics change so its place on the graph changes. Different places on the graph correspond to different stages of a star's life cycle. Here is an example of the three stages a star like the Sun goes through:

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Based on the class questions, which data are the focus for this activity?

we should focus on data related to time, size, temperature, and luminosity.

time, size, temperature, and luminosity.

3. Launch students into working on the *What Kinds of Stars Have Long and Stable Life Spans?* investigation in pairs.

4. As a class, make a determination about how to group the stars based on life cycle. While it can work for students to group the stars in different ways, it will be easier to have a whole-class conversation about findings if there is some agreement about what the groups are going to be. Use the grouping in *What Kinds of Stars Have Long and Stable Life Spans? Student Work* as a guide for the best way to do this.

Integrating Three Dimensions

This investigation provides an opportunity to engage with **SEP #2 - Developing and Using Models**. Students may not have an understanding that computational models are based on real data. This is highlighted in paragraph one of the text on the first page of the investigation handout. Be sure to unpack this enough so that students know this model is based on evidence. This is particularly important, since they will be using data generated from this model to make evidence-based claims.

5. Discuss with the class, and then have students fill in the top of the subsequent worksheets with their plans. The page for Group 1 has been completed for students as an example.

Star in a Box Computational Model

1. Students work through the investigation using the Star in a Box model to collect data about each group of stars. The groupings are based on what students figured out earlier in the Explore phase.

Conferring Prompts

Confer with students as they work in collaborative groups to collect data. These points should begin to surface in the work with the model, so that students see these overall points when they synthesize all their findings.

Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):
Clarifying the data they are collecting:
- During which stage(s) do stars change the least?
- During which stage(s) do stars change the most?
- What's the relationship between mass and lifespan in stars?
- What's the relationship between mass and stability? In other words, which stars' properties (temp, luminosity, size, etc) change the fastest? Low mass or high mass stars?
- According to the simulation, during which stage(s) do our Sun and other stars with one solar mass change the least?
- During which stage(s) do our Sun and other stars with one solar mass change the most?

Supporting the use of Patterns:
- How do you think the patterns in change you observed relate to our search for a star that can support a planet that might sustain life?
- What patterns did you notice as you observed the simulation of our Sun and other stars with one solar mass over time?
- How do you think the patterns in change you observed relate to our search for a star that can support a planet that might sustain life?

Integrating Three Dimensions

The kinds of connections students will make at this point should be informed by **CCC #1 - Patterns.**

The conferring questions provided here are intended to support students in seeing the big picture of the trend through the lens of Patterns, which will be discussed more explicitly in the Explain phase.. They are modified from STEM Teaching Tools #41 (http://stemteachingtools.org/brief/41)

Classroom Supports

Document student ideas and questions surfaced from the Domino Discover so students can refer back to them during the Explain phase.

Explore 1: What Kinds of Stars Have Long and Stable Life Spans?

See-Think-Wonder

See What do you see in the data?	**Think** What pattern did you observe in the data?	**Wonder** What do you think this pattern means?

4. After completing the investigation, pairs work together to record their ideas about the data in the **See-Think-Wonder** organizer. Frame this for students as a synthesis task: "What are your overall takeaways from the star in the box simulation? Consider what you know about the conditions that are necessary for humans to live on a planet and how much time it takes for life to evolve, then decide which group of stars are most likely to support a planet that sustains life. Be sure to provide evidence from the simulator and your reasoning about why that evidence matters."

5. 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.

6. If students don't surface one or more of the observations in *What Kinds of Stars Have Long and Stable Life Spans? Student Work*, display and run the Star in the Box simulation, using the suggested conferring questions from this Explore phase to have students surface those ideas. Once those observations are surfaced, the class is ready to move on to the Explain phase. If students do not point out that it is counterintuitive that stars with higher mass or more hydrogen die faster, highlight that observation and ask a few students to share their thoughts about it. This question about why high mass stars die faster can drive further investigation and will be answered by the end of the Elaborate phase.

Differentiation Point

Some students may struggle to articulate their observations in the data tables for this investigation. Support those students by including some sample student responses from below in their data tables, or using the sample student responses during conferring as models or examples.

Differentiation Point

Some students may have difficulty identifying all relevant patterns in their mathematical model. Differentiate for these students by including sentence starters in the See column of the See-Think-Wonder organizer that support them in identifying those patterns.

Look & Listen For

Listen for the following responses to the See-Think-Wonder, which are key to driving learning in the next phase

See

- Stars change the least during the main sequence stage and at the last stage of their life span
- Stars change very quickly after the main sequence until the end of their life spans
- The greater the mass of the star, the shorter the lifespan; or the lower the mass, the longer the lifespan
- The greater the mass of the star, the more rapidly properties like luminosity and temperature change; or the lower the mass, the slower properties like luminosity and temperature change

Think

- If we want to find a star that can support a planet that maintains liquid water for a long period of time, we need to look for stars that are in the main sequence stage
- If we want to find a star that can support a planet that maintains liquid water for a long period of time, we need to look for stars with low mass because they are more stable and last longer
- It's strange that high mass stars with more hydrogen die faster

Wonder

- Why do stars with more mass die faster?
- Why do stars with more mass change faster?
- How do we know which stars have low mass and are more stable with longer lifespans?
- How do we know which stars have high mass and are less stable with shorter life spans?

Explore 2

Making connections between observable star properties and lifespan

Students **develop and analyze a mathematical model** (the Hertzsprung-Russell Diagram) to look for **evidence of patterns** in the relationships between **observable star properties and lifespan**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Small groups	❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans?	None	❑ *HR Diagram Star Circles* ❑ *HR Diagram Graph Template* ❑ *How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans? Student Work*

Launch

1. Tell students that they will now investigate their questions about how to determine if a star has a low mass and will have a long and more stable life, or if it is high mass and will have a less stable and shorter life span. Let them know that they will need to figure out how to determine the mass of stars or if there are observable properties that give them clues about their life spans and stability.

2. Provide students with the set of star data as cut-out circles. Ask students how they would like to approach investigating relationships among mass, life span, stability, and other star properties. Prompt them to think about how they have looked for relationships between variables in their past math or science classes. Students may say they have graphed data or created tables to look for relationships. Support students in figuring out why creating a graph could be a helpful way to organize and make sense of data, as a transition into the *How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans?* investigation.

3. Let students know that what they will create now is a graph that is a static version of the computational model they used in the Explore 1. Tell them they will be plotting stars based on data at one moment in time, making it easier for them to see connections between stars' properties.

Implementation Tip

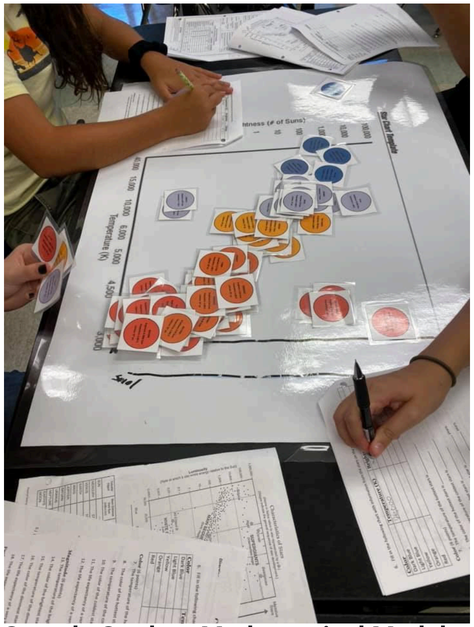
The star circle set has a total of 60 stars in the set. There are 22 data points representing real stars and their respective data. While the remainder of the star circles do not represent real stars, the range of star data seen in those circles was intentionally selected to ensure that when the set is plotted, the relative abundance of each type and color star closely reflects their relative abundance in the universe.

Integrating Three Dimensions

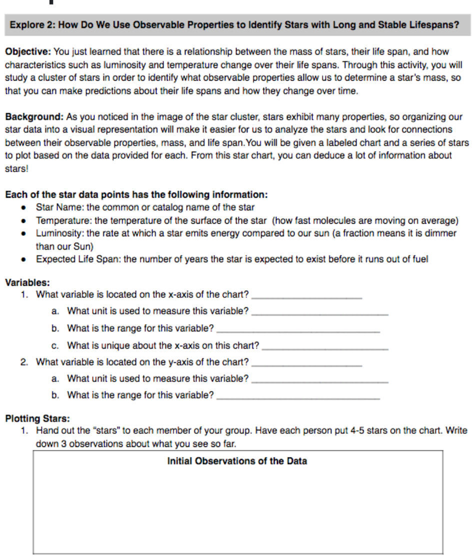
This launch is meant to prompt students to recall the usefulness of graphs and charts when trying to identify patterns in data, which is an important element of **CCC #1 - Patterns** at the middle school level. There is no need to explicitly address this element of patterns here, as it will be addressed again in the next 5E, but you can leverage this experience with graphing data when you get to that point. Students will also build upon this element of patterns during the next 5E, when they recognize that mathematical models are needed to identify some patterns, an important element of **CCC #1 - Patterns** at the high school level.

Investigating Relationships Between Star Properties

1. Have students get in small groups, and provide each group with a poster-size graph for plotting star data.



Sample Student Mathematical Model



Explore 2: How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans?

Objective: You just learned that there is a relationship between the mass of stars, their life span, and how characteristics such as luminosity and temperature change over their life spans. Through this activity, you will study a cluster of stars in order to identify what observable properties allow us to determine a star's mass, so that you can make predictions about their life spans and how they change over time.

Background: As you noticed in the image of the star cluster, stars exhibit many properties, so organizing our star data into a visual representation will make it easier for us to analyze the stars and look for connections between their observable properties, mass, and life span.You will be given a labeled chart and a series of stars to plot based on the data provided for each. From this star chart, you can deduce a lot of information about stars!

Each of the star data points has the following information:

- Star Name: the common or catalog name of the star
- Temperature: the temperature of the surface of the star (how fast molecules are moving on average)
- Luminosity: the rate at which a star emits energy compared to our sun (a fraction means it is dimmer than our Sun)
- Expected Life Span: the number of years the star is expected to exist before it runs out of fuel

Variables:

1. What variable is located on the x-axis of the chart? ____________
   a. What unit is used to measure this variable? ____________
   b. What is the range for this variable? ____________
   c. What is unique about the x-axis on this chart? ____________
2. What variable is located on the y-axis of the chart? ____________
   a. What unit is used to measure this variable? ____________
   b. What is the range for this variable? ____________

Plotting Stars:

1. Hand out the "stars" to each member of your group. Have each person put 4-5 stars on the chart. Write down 3 observations about what you see so far.

Initial Observations of the Data

Integrating Three Dimensions

The kinds of connections students will make at this point should be informed by **CCC #1 - Patterns.**

The conferring questions provided here are intended to support students in seeing the big picture of the trend through the lens of Patterns, which will be discussed more explicitly in the Explain phase. They are modified from STEM Teaching Tools #41 (http://stemteachingtools.org/brief/41)

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 Earth & Space Science Course Guide for support with this routine.

Classroom Supports

Document student ideas and questions surfaced from the Domino Discover so students can refer back to them during the Explain phase.

Explore 2: How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans?

See-Think-Wonder

See What do you see in the data?	**Think** What pattern did you observe in the data?	**Wonder** What do you think this pattern means?

2. Have students work in lab groups to record their ideas about the data in the **See-Think-Wonder** organizer.

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):

- Where do you see a trend developing?
- Are there any patterns in the graph? What is your evidence?
- Does the pattern point to possible relationships between star properties?
- What other star property seems to be associated with color?
- What do the pattern(s) tell you about the relationship between the temperature of a star and its luminosity?
- Are there any stars that don't fit the main trend line? Why do you think that is?
- What other properties of stars in the main trend line can we make inferences about by observing the color of the star?
- Does the pattern point to possible relationships between observable star properties and star lifespan?
- Which stars do you think are most likely to explode as a supernova?

3. Elicit student ideas through the group learning routine **Domino Discover**.

Look & Listen For

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

- There are connections between temperature and luminosity.
- Similar stars are clustered in similar places in the graph.
- Hotter stars are much more luminous / brighter
- More massive stars have a shorter expected lifespan
- Red stars have the longest expected lifespan while light blue stars have the shortest expected lifespan.
- Stars about the size of our sun or smaller have an expected lifespan of over 10 billion years.

4. If students don't surface one or more of the observations above, select one group's chart and use the suggested conferring questions from this Explore phase to have students surface those ideas. Once those observations are surfaced, the class is ready to move on to the Explain phase.

Differentiation Point

Some students may have difficulty identifying all relevant patterns in their mathematical model (HR-diagram). Differentiate for these students by including sentence starters in the 'See' column of the See-Think-Wonder organizer that support them in identifying those patterns.

Developing a Class List of Star Characteristics

1. Invite students to share their ideas around the following questions:
   a. What properties in stars allow us to make predictions about their life span and stability?
   b. What kind of stars live the longest and most stable lives?

2. Record students' ideas on a chart paper that can be referenced in subsequent class periods.

Classroom Supports

Develop the class consensus list around characteristics of stars likely to support an Earth-like Planet, as this will support student thinking when they analyze and interpret star data in order to argue from evidence about which stars are most likely to support an Earth-like planet.

Look & Listen For

The following ideas are critical to capture at this point because they are going to drive the work of the Explain phase.

- The mass of stars allows us to make predictions about their life span and stability.
- Properties like color, temperature, and luminosity give us clues about a star's mass, and therefore give us clues about their stability and life spans.
- Stars up to a solar mass of 1 are stable in the main sequence longer than it took for life to exist and evolve on Earth.
- Stars that have reached stages after the main sequence change a lot. Temperature and luminosity change so much that it would destroy life if it existed on any planet revolving around it.

Important Ideas to consider as we search for Stars that are Most Likely to Support an Earth-like Planet

The mass of stars allows us to make predictions about their life cycles.

Properties like color, temperature, and luminosity give us clues about a star's mass, and therefore their stability and life spans.

Stars up to a solar mass of 1 are stable in the main sequence longer than it took for life to exist and evolve on Earth.

Stars that have reached stages after the main sequence change a lot. Temperature and luminosity change so much, it would destroy life if it existed on any planet revolving around it.

3. If students are not surfacing some of the ideas above, have the class refer back to the See-Think-Wonder which should have captured ideas that will support them in sensemaking around the two prompts you provided.

Explain

Developing an explanatory model for patterns of stability and change observed in stars

Students use their understanding of **nucleosynthesis and gravity in stars** to **develop an explanatory model** for **stability and change** in **star life cycles** observed during the Explore phases.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Class Consensus Discussion	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ How and Why do Stars Change ❑ Summary Task	None	❑ *Why do some stars not fall in the main trend line?* ❑ Natural Reader Text to Speech ❑ *How and Why do Stars Change Student Work* ❑ Star Formation by Collapse of Molecular Clouds

Develop Explanatory Models

1. Provide some framing for the class about where we are in the investigation of stars: "During the Explore 2 phase, your class surfaced many patterns in the way different stars change over time. We began to discuss the implications these patterns have for your search for a star that can support a planet that might sustain life. But we figured out that we still have some questions about *how* and *why* we see these changes. This is a great example of how identifying patterns (like we did in the star graphs) helps us come up with new questions. Now let's figure out how forces within stars cause different groups of stars to change over time."

2. Tell students that they are now going to use the evidence and ideas they have gathered to develop an explanatory model for the changes that take place during the life cycle of a star.

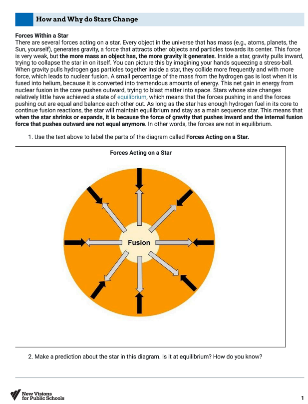
3. Ask students the following questions:
    a. What do you think causes stars to increase in energy?
    b. What do you think causes stars to increase in size?
    c. If the energy within a star is so high, why is all the hydrogen and helium gas they're made of not dissipating out into space? In other words, what force could be holding all the matter in stars together?

Look & Listen For

While students are responding, listen for these ideas, to provide a bridge to the text:
- Nuclear fusion caused the energy and size of stars to increase.
- Gravity is the force that holds them together.

4. Leverage student responses to transition into the text on page 1 of the *How and Why do Stars Change* handout. Tell them that reading this text will provide them with some additional details about the forces that govern changes within a star, which they will use to develop their explanatory models for changes that take place during a star's life cycle.

5. Have students independently read the text using the following **text annotation** strategy:
    a. Circle any information that you think will help explain why a star's size increases over time
    b. Underline any information that you think will help explain why a star's size decreases over time
    c. Box any information that you don't understand or have questions about. Jot those questions in the margin.



How and Why do Stars Change

Forces Within a Star
There are several forces acting on a star. Every object in the universe that has mass (e.g., atoms, planets, the Sun, yourself), generates gravity, a force that attracts other objects and particles towards its center. This force is very weak, but **the more mass an object has, the more gravity it generates**. Inside a star, gravity pulls inward, trying to collapse the star in on itself. You can picture this by imagining your hands squeezing a stress-ball. When gravity pulls hydrogen gas particles together inside a star, they collide more frequently and with more force, which leads to nuclear fusion. A small percentage of the mass from the hydrogen gas is lost when it is fused into helium, because it is converted into tremendous amounts of energy. This net gain in energy from nuclear fusion in the core pushes outward, trying to blast matter into space. Stars whose size changes relatively little have achieved a state of equilibrium, which means that the forces pushing in and the forces pushing out are equal and balance each other out. As long as the star has enough hydrogen fuel in its core to continue fusion reactions, the star will maintain equilibrium and stay as a main sequence star. This means that **when the star shrinks or expands, it is because the force of gravity that pushes inward and the internal fusion force that pushes outward are not equal anymore**. In other words, the forces are not in equilibrium.

1. Use the text above to label the parts of the diagram called **Forces Acting on a Star.**

Forces Acting on a Star

2. Make a prediction about the star in this diagram. Is it at equilibrium? How do you know?

Integrating Three Dimensions

The teacher really needs to act as a facilitator, helping the class navigate from the patterns that came up in the last phase to a need to know about the causal mechanism behind those patterns. It is important to connect the questions for this phase directly to ideas that students raised, or to questions specific students brought up. This, again, provides students with practice in using the **CCC of Patterns** hand in hand with the **SEP of Models**.

Access for Multilingual Learners

Allowing students to explain phenomena by developing an explanatory model provides access for **emerging English language learners:** they are able to demonstrate understanding through visuals, in this case force diagrams.

Differentiation Point

Some **English Language Learners** and **below level readers** may struggle with fluency when reading this or other texts. Allow those students to use a device that has the Chrome extension Natural Reader Text to Speech, which reads the text aloud as it highlights the words. This will allow struggling readers to focus on comprehending important concepts instead of having to focus most of their efforts on reading fluently.

Implementation Tip

If students learned about force diagrams in middle school, then this understanding may surface in the class discussion. Students do not need to understand about vectors and magnitude to create a useful model for this lesson. They just need a shared way of communicating the relative size of the forces in a star.

6. Have students explain their annotations to a partner, then label the diagram as prompted. Circulate as students are discussing what they are figuring out.

Look & Listen For

While students are talking in pairs, listen for the following points:

Gravity

- There is a direct relationship between mass and gravitational pull
- Gravity affects the size of a star by pulling gases inward toward the center of mass

Nuclear Fusion

- When gravity pulls hydrogen gas particles together within a star, they collide more frequently and with more force, which leads to nuclear fusion
- A small percentage of the mass from the hydrogen gas is lost when it's fused into helium, because it is converted into tremendous amounts of energy.
- This energy is much more than what was required to make the fusion happen
- This net gain in energy from nuclear fusion in the core pushes outward

7. Support the development of explanatory models for why a star's size changes over time by showing the video, *Star Formation by Collapse of Molecular Clouds*, and asking students to note observations.

8. Elicit observations and ask students which force they think is driving what they observed. The net movement of matter in the video is inward, so listen for students to say gravity.

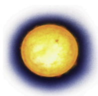
9. Use student responses to decide how to depict the magnitude of the force of gravity vs. fusion force with arrows. In other words, draw arrows with a length that represents the relative magnitude of each force on the molecular cloud image in the Explain handout.

10. Elicit student responses to demonstrate how to explain what is taking place in words. The class should arrive at an explanatory model that connects this early stage in a star's life to massive gravitational pull.

Explain: How and Why do Stars Change?

Forces acting on a star lead to changes over their life cycles. Draw the forces pushing outward and inward at each stage of a star's life cycle. For each stage, decide on the size of gravity and fusion pressure arrows you want to draw so that they reflect the pattern in size change you observed during each stage.

Hydrogen gas and dust cloud forms new stars.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why new stars form from a hydrogen and dust cloud. Don't forget to include evidence to support your claim.
	

Stars change very little while they are in the Main Sequence stage.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why stars change very little while they are in the main sequence stage. Don't forget to include the evidence to support your claim.
	

11. Confer with students as they complete the rest of their explanations about why a star's size is either staying the same, increasing, or decreasing at the various stages of its life cycle in the Explain handout, including the prompts on the last page of the Explain handout.

Look & Listen For

As students are completing their responses, look and listen for these ideas, which will be important to surface in the Class Consensus Discussion:

- Stars are most stable when they are in the main sequence stage. This is when we observed their properties like temperature, luminosity and size change the slowest.
- Stars spend the majority of their life cycles in the main sequence stage. I saw that all stars spend about 90% of their time in the main sequence.
- The most massive stars spend the least time in the main sequence stage. 1 solar mass stars spend 8992.81 million years, 4 solar mass stars spend 178.91 million years, and 40 solar mass stars spend 4.87 million years.
- This helps us understand why more massive stars die fastest and less stable because we know they spend less time in the main sequence stage than lower mass stars, which is the stage where stars spend about 90% of their life cycles.
- In the data, it shows that all hydrogen fuel is converted into helium faster in more massive stars. It takes 19.5 million years for 10 solar mass stars, 300 million years for 3 solar mass stars, and 10 billion years for 1 solar mass stars. High mass stars have shorter life spans because they burn through their hydrogen fuel faster.
- Higher mass stars have higher luminosities (release more energy per second) because they fuse hydrogen faster, which releases energy.

Differentiation Point

It is likely that some students noticed and had questions about the stars with higher or lower luminosity than other stars with the same temperature (stars not on the main trend line). If students complete their Explain handout early and demonstrate mastery, have them investigate why some stars did not fall on the main trend line by completing the *Why do some stars not fall in the main trend line?* handout found in the additional materials section at the end of this teacher guide.

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 explanations, based on evidence. It is really important for us to get to some agreement on how we represent what we know about different stars' life cycles, 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.

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

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 provide an opportunity for groups to share out around their sensemaking and for other groups to list, summarize, and ask questions after each share.

We recommend you have groups display their explanatory models while they share their ideas. A discussion with no visual component can leave out a number of students.

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 different stars work, and why they have different life cycles. 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.

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 Patterns in figuring out which claim is best supported. Some prompts you might provide are:
    a. Why do more massive stars die faster than less massive stars?
    b. How does the rate of star death relate to luminosity of a star (amount of energy released per second)?
    c. What factors lead to a star's stability or instability? Why is it important to understand how long a star is stable and when it might change?

d. What did you learn from the How the Sun Works investigation that you needed to know in order to explain what causes some stars to be stable and some stars to change?

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. Annotate terms on a shared H-R diagram, so that they can serve as a reference for the class.

Take Time for These Key Points

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

- Stars with higher mass fuse hydrogen into helium faster.
- Stars with higher mass seem to burn up faster.
- There are more lower mass stars because they use fuel so slowly and they have a longer life span.
- Gravity pulls matter inward, and the energy from fusion creates outward forces. A star's stability depends on whether these forces are equal or not, and how long they are in that state.
- We had to study stars at the scale of one star (our Sun) and many stars (supercluster) in order to have all the information needed to explain what causes stars to be stable and what causes them to change. If we would have only studied the sun, we only would have observed the pattern in the Sun's spectra that led to our understanding of the role of nuclear fusion, but we would not have seen the patterns of how stars change and the relationship with mass.

Key points that are not yet figured out (that are addressed in the next part of this 5E lesson):

- Why do higher mass and lower mass stars undergo fusion at different rates?
- How does gravity relate to the lifespan of a star?

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 star life cycles;
   b. changed based on our investigation of star life cycles;
   c. added based on our investigation of star life cycles.

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:
   - Why do stars with higher mass fuse hydrogen into helium faster?
   - Can gases burn?

Integrating Three Dimensions

The prompt about patterns in the Class Consensus Discussion is in support of students' use of **CCC #1 - Patterns**, specifically the idea that different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. So far stars have been investigated at the scale of our solar system (How the Sun Works) and of a super cluster (Star in a Box). Patterns identified at both scales were necessary to make sense of why stars change. The idea of observing patterns on different scales will be further developed in the Elaborate phase when students observe patterns at the atomic scale when investigating nuclear fusion in stars.

Prompt c is meant to support students' use of **CCC #7 - Stability and Change** and is modified from STEM Teaching Tools #41 (http://stemteachingtools.org/brief/41).

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.

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 circle back to the ideas in this text, in the coming parts of the 5E sequence.

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, life cycle of stars; 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.

Refining our Criteria for Evidence-Based Claims

1. Prompt students to revisit the class consensus list on evidence-based claims. Say: *Think about the ideas you surfaced regarding what makes a star more likely to support an Earth-like planet. Those are claims based on evidence. What made those evidence-based claims?*

2. Through class discussion, surface new ideas, as well as ideas students are finding particularly helpful or important, and record those on the class consensus list.

Classroom Supports

Continue to develop the class list, as this will support student thinking about evidence-based claims throughout the unit.

What Counts as an Evidence-Based Claim?

You found information from a book or a reliable source.

The evidence comes from an experiment or investigation you did.

The claim is not just someone's opinion.

Many scientists can agree on that interpretation.

Patterns in data can count as evidence for a claim. But you have to have evidence for the pattern too.

Evidence for a claim comes from other scientists' data.

Evidence for a claim comes from patterns observed in models based on data.

A model based on evidence, like a diagram that shows how something works.

Elaborate

Using a model of nucleosynthesis in stars in order to explain differences in stability and change in stars

Students collect data from a **computational model of nucleosynthesis in stars** in order to **identify patterns** in the relationship between **mass of a star** and **nucleosynthesis**. They **use these patterns** to **explain why stability varies** across stars of different mass, and why **higher mass stars are able to produce heavier elements**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Think-Talk-Open Exchange ❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Why do more massive stars change and die faster? ❑ How are elements heavier than iron produced?	None	❑ Stephan Hawking - Supernovas ❑ Iron [26] Game

Launch the Fe-26 Game

1. Remind students that at the end of the Explain phase it was established that the class has made a claim (massive stars die and change faster than less massive stars because the rate of fusion is faster) based on evidence (rate of hydrogen fusion into helium data in stars of different masses), but they still do not have scientific reasoning to complete their explanations.

2. Ask the following question:
    - How should we investigate why the rate of fusion is faster in massive stars than in less massive stars?

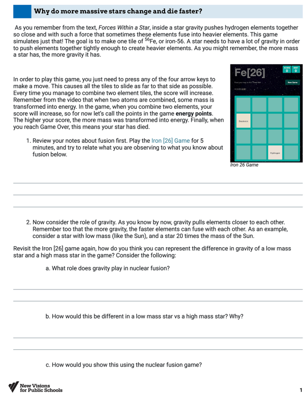
Listen for students to say that a model of fusion in stars would be useful for the investigation. If students don't ask for a model on their own, prompt them to think about how they have been able to make observations of processes that are otherwise unobservable during previous parts of this star life cycles investigation. Star in a Box was an example of a computational model of star life cycles.

3. Introduce the game called *Iron [26]* that will allow students to model nuclear fusion in stars. Provide students with the Elaborate handout and organize them into groups of two.

4. Have students complete the first page of the *Why do more massive stars change and die faster?* handout, where they will read the intro text , play with the Iron [26] game, and brainstorm ideas for how

they can use the game to model nuclear fusion in a high and low mass star.

5. Facilitate a discussion in order to agree how the class should model fusion in a lower mass star vs. a high mass star.



Why do more massive stars change and die faster?

As you remember from the text, *Forces Within a Star*, inside a star gravity pushes hydrogen elements together so close and with such a force that sometimes these elements fuse into heavier elements. This game simulates just that! The goal is to make one tile of ^{56}Fe, or iron-56. A star needs to have a lot of gravity in order to push elements together tightly enough to create heavier elements. As you might remember, the more mass a star has, the more gravity it has.

In order to play this game, you just need to press any of the four arrow keys to make a move. This causes all the tiles to slide as far to that side as possible. Every time you manage to combine two element tiles, the score will increase. Remember from the video that when two atoms are combined, some mass is transformed into energy. In the game, when you combine two elements, your score will increase, so for now let's call the points in the game **energy points**. The higher your score, the more mass was transformed into energy. Finally, when you reach Game Over, this means your star has died.

1. Review your notes about fusion first. Play the Iron [26] Game for 5 minutes, and try to relate what you are observing to what you know about fusion below.

Iron 26 Game

2. Now consider the role of gravity. As you know by now, gravity pulls elements closer to each other. Remember too that the more gravity, the faster elements can fuse with each other. As an example, consider a star with low mass (like the Sun), and a star 20 times the mass of the Sun.

Revisit the Iron [26] game again, how do you think you can represent the difference in gravity of a low mass star and a high mass star in the game? Consider the following:

a. What role does gravity play in nuclear fusion?

b. How would this be different in a low mass star vs a high mass star? Why?

c. How would you show this using the nuclear fusion game?

Look & Listen For

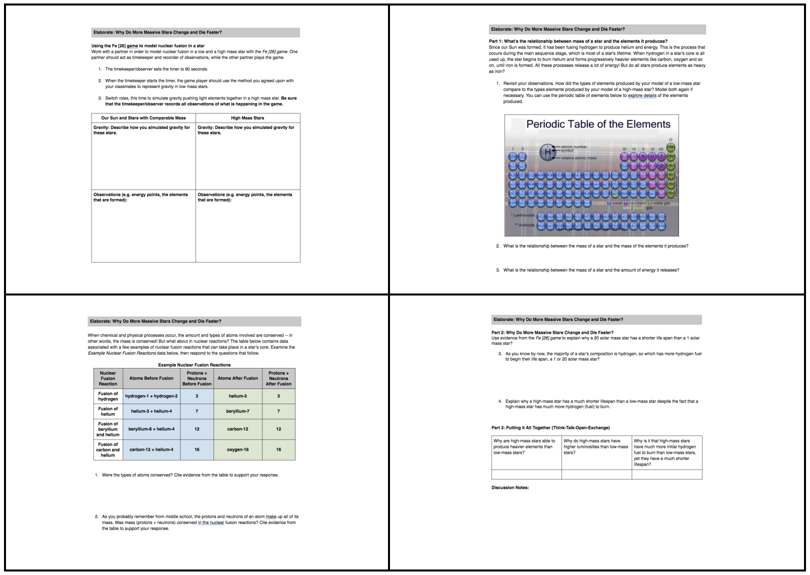
While students are sharing responses, listen for these ideas:

- Gravity pulls hydrogen together which leads to nuclear fusion
- Gravity is stronger in high mass stars than in low mass stars because it the amount of gravity in a star is due to the amount of mass
- Since tapping the keys pulls element tiles together, and gravity is stronger in a high mass star, we should tap the keys faster.

5. Once the class has agreed on the ideas above, ask students whether they think gravity pulls hydrogen atoms together strategically or randomly. Listen for students to say randomly, then ask them how they can represent the force of gravity in a random way. Listen for students to say push the keys randomly without looking.
6. The remaining parts of the activity can be completed in pairs, once students are clear on the agreed-upon ways to use the Fe-26 game.

Using the Fe-26 Game to Gather Evidence

1. Confer with student pairs as they complete the next four pages of the *Why do more massive stars change and die faster?* handout.



Implementation Tip

Confer with students as they work in pairs to collect data and complete the handout.

Suggested conferring questions (these should push students' thinking around establishing relationships, observing patterns, identifying variables, and questioning events):

- Which stars produce the heaviest elements? High or low mass stars?
- Why do you think high mass stars are able to produce heavier elements?
- Which is able to produce more energy (points), a low-mass star or a high-mass star? Why do you think that is the case?
- Which stars had shorter life spans? High or low mass stars?
- What role is gravity playing in the lifespan and changes in than a low-mass star despite the fact that it starts off with much more hydrogen fuel?

It may also be important to remind students about the characteristics of a complete, mechanistic explanation:

An explanation needs to answer *how* and *why* something happens. For this lesson, that includes the following points:

- How gravity leads to nuclear fusion
- How the rate of fusion in a high mass star compares to the rate of fusion in a low mass star
- Why a high-mass star has a much shorter lifespan than a low-mass star despite the fact that a high-mass star has much more hydrogen (fuel) to burn

Making Sense of the Evidence

1. Mix up the student pairs, so that students are in triads with people they have not worked with on the Fe-26 game.
2. Have the groups complete a **Think-Talk-Open Exchange** to help students articulate their ideas in response to the following questions:
    - Why are high-mass stars able to produce heavier elements than low-mass stars?
    - Why do high-mass stars have higher luminosities than low-mass stars? Remember, luminosity is the amount of energy that is released by a star per second. Consider how the energy is produced.
    - Why is it that high-mass stars have much more initial hydrogen fuel to burn than low-mass stars, yet they have a much shorter lifespan?
3. Have students share out their ideas.

Look & Listen For

While students are sharing responses, listen for these ideas:
- There is more gravity in high mass stars, which pulls elements together with greater frequency and force
- Since elements are being pulled together with greater frequency and force, nuclear fusion, which releases energy, is happening at a faster rate
- Although high mass stars have much more initial hydrogen fuel to burn than low mass, due to gravity they burn that fuel so much faster than low mass stars that they run out of fuel faster.

Implementation Tip

This is the first time the group learning routine **Think-Talk-Open Exchange** appears in this unit. It's a structured discussion routine that allows students the opportunity to share with others and gain feedback on their ideas by finding similarities and differences, piecing together disparate bits of information, or reconciling different interpretations. Refer to the Earth & Space Science Course Guide for support with this routine. The student handout also provides some support with enacting this routine.

4. Have students work in pairs to complete the page *How are elements heavier than iron produced?*
5. Use the Group Learning Routine, **Domino Discover**, to surface the thinking across the room. The class should arrive at the conclusion that a supernova explosion generates more energy than any star can, allowing for the fusion of the heaviest elements.
6. Show the video, Stephan Hawking - Supernovas, to bring closure to the investigative phenomenon for this 5E.
7. Assess student understanding of **CCC #1 Patterns** independently by asking each student to respond to the following prompt:

Access for Multilingual Learners

Using Think-Talk-Open Exchange at this stage provides support for English Language Learners who are **emerging** and **transitioning ELLs.** Providing different types of unique comprehensible input, all from peers in the classroom, supports students' language development.

Integrating Three Dimensions

Students identified evidence of patterns in light spectra from at the scale of the solar system (our sun), and the scale of a star supercluster, then were prompted to reflect about the importance of studying stars at these different scales during the Class Consensus Discussion and Summary Task during the Explain phase. In this phase students identified patterns at the atomic scale and needed to use patterns at all these scales to complete their explanations of star stability and change. The prompt in step 7 is designed to assess and support further development of their understanding of this important element of **CCC #1 Patterns**.

- Why was it important to study stars at the scale of the supercluster (Star in a Box and Mapping Stars), of one star (How the Sun Works), and at the atomic level (Fe-26) in order to explain the phenomenon of star stability and change?
- Would we have been able to explain how and why stars change and why the most massive stars change fastest without studying stars at all three scales?

Evaluate

Constructing arguments for which star is most likely to support a planet that can sustain life

Students **critique and revise their models** for why Earth has been an ideal planet for sustaining life **using evidence** about star **stability**. They **use evidence** about how and why **our Sun and other stars change or remain stable over time** to **argue** about which star in the performance task data set is most likely to support an Earth-like planet.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Small groups of 3-4 students (same groups from Unit Launch)	❑ Idea Carousel	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Star Life Cycles Model Rubric ❑ Star Life Cycles Argument Rubric ❑ Star Life Cycles	None	❑ Driving Question Board ❑ Groups' revised models (charts) ❑ Class wide evidence-based claim poster ❑ *Performance Task Organizer Student Work*

Revise and Share Models

1. Have students revisit the life on Earth time scale from the Anchor Phenomenon and respond to the following questions independently:
   - What do we need to know about other stars to determine if they are as stable as our Sun?
   - What are the factors that contribute to a planet's stability for supporting life?

2. Ask students to consider their responses to these questions and what they have figured out about star life cycles, then represent their ideas about why the Sun has been able to support a planet where life has been able to exist and evolve on their initial group models from the performance task launch. These should go onto new pieces of chart paper.

3. 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:
   - ✔ Write a check on post its with comments about ideas represented in the model that resonate.
   - **+** Write a plus symbol on post-its with comments about ideas that should be added to the model.

Access for Multilingual Learners

The routine **Idea Carousel** is ideal for **emerging language learners**. Students with only receptive language can simply engage by listening and adding annotations

- **?** Write a question mark on post-its with comments about ideas that you don't think are relevant to the model.
- **Δ** Write a delta symbol on post-its with comments about suggestions for how to clarify an idea or represent it more clearly.

Implementation Tip

The two questions in this Evaluate phase launch are critical to transitioning from this 5E sequence to the next one. This is how you create a "need to know" around what's going to happen to our Sun in the future. If students have already brought up these questions, then they can be rephrased or asked differently.

Implementation Tip

This routine allows for each group to give and receive warm feedback and suggestions around content and clarity in their model, as well as pose and respond to questions. The repeated use of **Idea Carousel** should support students in gaining familiarity with the routine and getting better at using it as a tool to surface thinking.

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.

- Our Sun is a star that has provided the Earth with the right amount of energy for liquid water to exist for 5 billion years.
- Over those 5 billion years, life has been sustained on Earth.
- The stability of energy has made Earth a place where humans and other species can survive.
- Fusion force and gravity in the Sun are in equilibrium so it is stable.
- The Sun has been so stable for such a long time because it is a relatively small star, so it changes slower than more massive stars.

3. 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.

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

Return to the Performance Task

1. Using what they learned in the Idea Carousel, have students independently refine their models in their *Star Life Cycles*. See the sample response for an idea of the types of responses to expect at this stage in the unit.

2. After students complete their work, support them to use the rubric for this learning sequence as a self-reflection tool. Here are some ways the rubric can be used:
    a. Have students complete a self-assessment using the rubric.
    b. Create a piece of student work that is a fictional composite of a few different students' work, and complete a critique as a class, while students critique their own work using the rubric.
    c. Collect all the work and score the work, with an eye to how accurate students' self-assessments seem to be.

3. Assign students to partnerships and have them review one another's work and self-assessment and provide feedback on the accuracy of the self-assessment.

4. Give each student an opportunity to revise their model using what surfaced from their self-assessment and/or feedback.

Implementation Tip

Below are notes about what makes stars in the performance task data set either likely or unlikely to support a habitable planet.
Eta Carinae: Blue Giant; extremely high temperature; high mass indicates short lifespan; extremely unlikely that plant life could develop on any planets that might be revolving around it.
Gliese 440 is a White Dwarf, and has an extremely low luminosity.
Kepler-432: Red Giant; temperature changes relatively fast and planets that revolve around it will be engulfed by this star in a relatively short period of time.

Trappist-1, Kepler 442, Kepler-18, Kepler-79, TOI-2257, Kepler-186, HD 20782: These are Main Sequence stars that have a mass comparable to or less than our Sun, meaning they have life spans of 10 billion years or more and their properties are stable for 9 billion years or more. Therefore if a planet orbits around one of these stars within the habitable zone, humans can settle there for a long time and plant and animal life may have had time to appear.

Access for All Learners

All students have observed stars and/or seen them in the media at some point in their lives. The prompts at the end of the rubric are designed to support students in pausing to reflect about why their new ideas are relevant to their lives. After students complete the reflection prompts independently, consider facilitating a whole-class share around why learning during this 5E is relevant to students' lives and displaying their responses somewhere in the classroom. This can foster relevance and belonging for all students.

Revisit the Driving Question Board

1. Revisit the Driving Question Board questions and have students work in pairs to identify what they have figured out and what they still need to investigate, then generate at least one new question related to finding an Earth-like planet.

2. Use the Group Learning Routine **Domino Discover** to hear different pairs' ideas.

Look & Listen For

While students are engaged in the Domino Discover, listen for the following questions that can be used to transition to the next investigation:

- How far do the planets that revolve around the stars we have identified orbit from those stars?
- What is the temperature of those planets?
- Do those planets have liquid water?
- Do those planets have life?
- Is there an atmosphere on those planets?
- Are those planets terrestrial or jovian?

3. Use questions like the ones above or any other questions related to planet characteristics and whether they have liquid water to transition to the next 5E investigation. Say "I'm noticing a lot of questions related to planet characteristics and whether they have liquid water, so tomorrow I will have some resources available for the class to investigate these questions."

Standards in Star Life Cycles 5E

Performance Expectations

HS-ESS1-1 **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun’s core to release energy in the form of radiation.**
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun’s core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun’s radiation varies due to sudden solar flares (“space weather”), the 11-year sunspot cycle, and non-cyclic variations over centuries.
Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun’s nuclear fusion.

In NYS, all occurances of the term "sun" in this PE have been formatted as "Sun."

HS-ESS1-3 **Communicate scientific ideas about the way stars, over their life cycle, produce elements.**
Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.
Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.

In NYS the clarification statement has been edited as follows: Emphasis is on the way nucleosynthesis varies as a function of the mass of a star and the stage of its lifetime.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3) • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. SEP2(7) 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.A The Universe and Its Stars • The star called the Sun is changing and will burn out over a life span of approximately 10 billion years. ESS1.A(1) • 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) • 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) PS3.D Energy in Chemical Processes and Everyday Life • Nuclear fusion processes in the center of the Sun release the energy that ultimately reaches Earth as radiation. PS3.D(1)	Patterns • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. CCC1(1) Energy and Matter • In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. CCC5(5) 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 1 & 2	Explain	Elaborate	Evaluate
Developing and Using Models		See-Think-Wonders 1 & 2	How and Why Stars Change		Revised Performance Task models
Constructing Explanations and Designing Solutions			Class Consensus Discussion	Think-Talk-Open Exchange	
ESS1.A The Universe and Its Stars			How and Why Stars Change	Think-Talk-Open Exchange Domino Discover	Revised Performance Task models Star Argument
PS3.D Energy in Chemical Processes and Everyday Life	Domino Discover		How and Why Stars Change	Think-Talk-Open Exchange Domino Discover	Revised Performance Task models
Patterns			Summary Task Prompts 1 & 2	Think-Talk-Open Exchange	Revised Performance Task models
Energy and Matter	Domino Discover	See-Think-Wonders 1 & 2		Task: Why Do More Massive Stars Change and Die Faster?	
Stability and Change	Domino Discover	See-Think-Wonders 1 & 2	Summary Task Prompts 3 & 4		Revised Performance Task models Star Argument

Common Core State Standards Connections

	Engage	Explore 1 & 2	Explain	Elaborate	Evaluate
Mathematics		MP2 MP4			
ELA/Literacy		RST.9-10.7 WHST.9-10.9 SL.9-10.5	RST.9-10.7 WHST.9-10.1 SL.9-10.4	RST.9-10.1 RST.9-10.7 WHST.9-10.9 SL.9-10.4	WHST.9-10.1 WHST.9-10.9 SL.9-10.4 SL.9-10.5

Student Work for Star Life Cycles 5E

What Kinds of Stars Have Long and Stable Life Spans? Student Work

Group the Stars Based on Life Cycle

Run the simulation on "fast" for stars of all solar masses in the simulation. Indicate below how you would group the stars based on the stages they go through.

Group	**Group 1 (our Sun and stars like our Sun)**	**Group 2**	**Group 3**
Stages of Life Cycle	1. Main Sequence 2. Red Giant 3. White Dwarf	1. Main Sequence 2. Red Giant 3. Neutron Star	1. Main Sequence 2. Red Giant 3. Blue Giant 4. Black Hole
Group Which masses fall in this group?	.2, .65, 1, 2, 4, 6	10, 20	30, 40

Group 1: Our Sun and Stars with Comparable Mass

Set the simulation to 1 solar mass. Observe how our Sun and stars with comparable masses are likely to change during the different stages of their life cycles.

Stage	Main Sequence	Red Giant	White Dwarf
Time in this stage	About 9 billion years	About 1.3 billion years	A very long time
Change in size	It stays about the same size as the sun currently is for nearly 9 billion years.	It gets a lot bigger than the current size of the sun and it increases faster than in the main sequence during about a 1.3 billion year span. Then it gets a lot smaller than the current size of the sun very quickly.	It's a small size and stays that size.
Change in temperature	The temperature changes very little from the current temperature for almost 10 billion years.	The temperature decreases slightly and very slowly during the first 1 billion years, then increases a lot and quickly over the next 300 million years, reaching temperatures of over 60,000 K.	The temperature is lower than the sun currently is and it stays that way.
Change in luminosity	The luminosity stays at one solar luminosity for about 7.5 billion years.	The luminosity changes quickly and a lot compared to when it was in the main sequence.	The luminosity goes down very fast to a luminosity much lower than the current luminosity of our sun (maybe no luminosity) and it stays there.
Change in mass	The current mass doesn't seem to change for about 9 billion years.	The mass decreases faster and faster during this stage and as the sun gets bigger in diameter.	At this point the mass has already decreased to almost half the current mass and it does not change.

See-Think-Wonder

See What pattern did you observe in the data?	**Think** What do you think this pattern means?	**Wonder** What questions do you have about the pattern?
• Stars change the least during the main sequence stage and at the last stage of their life span. • Stars change very quickly after the main sequence until the end of their life spans. • The greater the mass of the star, the shorter the lifespan. Or the lower the mass, the longer the life span. • The greater the mass of the star, the more rapidly properties change like luminosity and temperature change. Or the lower the mass, the slower properties change like luminosity and temperature change.	• If we want to find a star that can support a planet that maintains liquid water for a long period of time, we need to look for stars that are in the main sequence stage. • If we want to find a star that can support a planet that maintains liquid water for a long period of time, we need to look for stars with low mass because they are more stable and last longer. • It's strange that high mass stars with more hydrogen die faster.	• Why do stars with more mass die faster? • Why do stars with more mass change faster? • How do we know which stars have low mass and are more stable with longer life spans? • How do we know which stars have high mass and are less stable with shorter life spans?

How Do We Use Observable Properties to Identify Stars with Long and Stable Lifespans? Student Work

See-Think-Wonder

See What pattern did you observe in the data?	**Think** What do you think this pattern means?	**Wonder** What questions do you have about the pattern?
• All of the colors are clustered together (with similar colors). • The main trendline (main sequence) shows that temperature of a star increases as luminosity increases. • Among stars in the main trend line, those with the highest temperature and luminosity have the shortest expected life spans. • Among stars in the main trend line, those with the lowest temperature and luminosity have the longest expected life spans. • Among stars in the main trend line, red stars have the longest expected life spans, while blue stars have the shortest expected life spans. • Some stars have much higher or lower luminosity than stars of the same temperature (not on the main trend line).	• I think there's a relationship between temperature and color. • I think there's a relationship between temperature and luminosity. • I think that among stars in the main trend line, red stars have the lowest initial mass, while blue stars have the highest initial mass • I think temperature and luminosity might be related to how fast a star dies. • I think that the color of a star on the main trend line can help us determine their mass, and therefore their stability and life span.	• why do some stars have much higher or lower luminosity than stars of the same temperature? • what does temperature and luminosity have to do with star stability and life span? • which stars in our data set are red, orange, or blue?

Performance Task Organizer Student Work

What makes Earth habitable?

After discussing how you would change your initial model with your group based on what you figured out about star life cycles, record your revised model for what makes Earth habitable. Be sure to represent your understanding of how the Sun is able to release the right amount of heat and energy for the right amount of time to support the existence of life on Earth. Consider and respond to the following reflection prompts before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. Why was explaining the *stability and change* of stars useful in revising your model? Why might it be useful to explain *stability or change* when investigating other phenomena?

once we were able to explain the stability and change in different stars and how it's related to specific characteristics, we were able to explain why our Sun has been stable for so long allowing for the existence of liquid water and for life to evolve on Earth. we think that when we study other phenomena, being able to explain stability or change in those phenomena might help us explain other things and make predictions about those phenomena.

2. How did studying stars at different *scales* of our galaxy (solar system, supercluster, atomic) support you in revising your model?

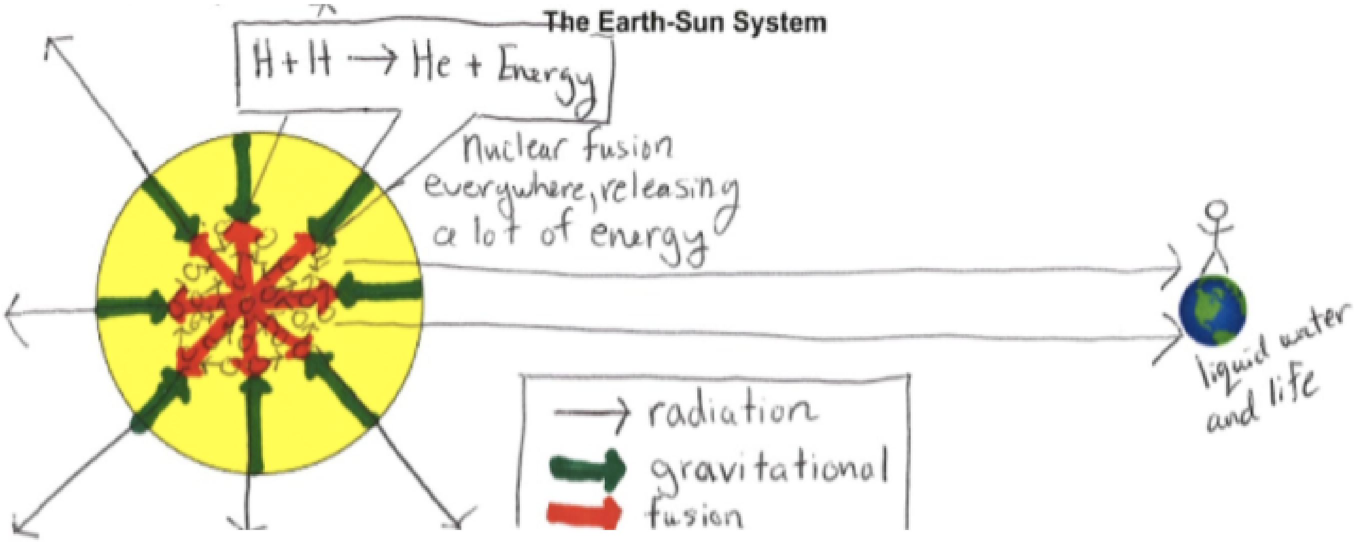
we had to study stars at the scale of one star (our Sun), many stars (supercluster), and at the atomic scale in order to have all the information needed to explain what causes stars to be stable and what causes them to change. If we would have only studied the Sun's spectra, we only would have figured out the Sun's composition which led to our understanding of the role of nuclear fusion, but we would not have seen the patterns of how stars change and the relationship with mass.

Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your model for why Earth is a planet that can sustain life.

Change to the Model	Evidence	Scientific Reasoning
we added fusion and gravitational force arrows. we represented fusion force arrows pointing outward from the center and the gravitational force arrows pointing inward. Each arrow has an equal amount of force.	when we used the Star in a Box computational model we noticed... -stars are the most stable when they are in the main sequence stage. -the greater the mass of the star, the shorter the lifespan. -the greater the mass of the star, the more rapidly properties change like luminosity and temperature change. -stars that have a mass comparable to the Sun have lifespans of about 10 billion years and stay stable in the main sequence for about 9 billion years. when we plotted stars from the supercluster we noticed... -stars with the highest temperature and luminosity have the shortest expected life spans and those with the lowest temperature and luminosity have the longest expected life spans. The Sun is a relatively low mass star and has a relatively low temperature and luminosity. The Sun has been stable for about 5 billion years.	The fusion force causes the Sun to expand and the gravitational force causes the Sun to contract. when fusion force and gravitational force are in equilibrium, stars are stable. High mass of a star causes it to have more gravitational force which fuses hydrogen together at a faster rate.

2. In the space below, draw a revised version of your model for why Earth is a planet that can sustain life below.

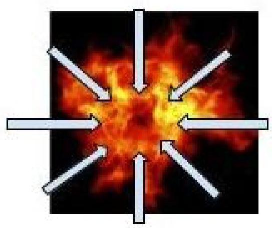


Sample Student Argument - Performance Task Organizer

Kepler 36 is the star most likely to support a planet that can sustain life. It has a temperature of 5,911 Kelvin which is closest to the temperature of the sun, 5778 Kelvin. It's luminosity of 1.26 suns is second closest to our sun's luminosity. This is important because using our model from the Explore 2 phase, we were able to infer that Kepler 36 has a mass comparable to our Sun, and therefore its life span will be about 12 billion years and the amount of time it has stable properties like size, temperature and stability should be about 10 billion years. This means it could potentially host an Earth-like planet where humans can live without major changes to the star that would destroy us. The scale of time Kepler 36 is stable also means that a planet at the right distance could sustain plant and animal resources, which could support human survival on the planet.

How and Why do Stars Change Student Work

Sample Student Response: Formation of new stars

Hydrogen gas and a dust cloud form new stars.	**Explanation** Be sure to discuss the role of the force of gravity and/or fusion force in your explanation for why new stars form from a hydrogen and dust cloud. Don't forget to include evidence to support your claim.
	I think the force of gravity is much stronger than fusion force in a star nebula. In the animation, the hydrogen and dust cloud is coming together and getting smaller. Since we know that the force of gravity causes star material to come together and fusion pressure causes the star material to spread further part, I can conclude that the force of gravity was the main driving factor at this stage of the star's life cycle.

Classroom Resources for Star Life Cycles 5E

HR Diagram Star Circles
Why do some stars not fall in the main trend line?
HR Diagram Graph Template
Blank Star Circles

HR Diagram Star Circles

Use this master to create stars for the graphing activity.

Sun
Luminosity: 1 Sun
Temperature: 5,778 K
Lifetime: 10 billion yrs

SDC2019
Luminosity: 0.8 Suns
Temperature: 5,900 K
Lifetime: 10 billion yrs

CPDLM200
Luminosity: 1 Suns
Temperature: 5,900 K
Lifetime: 10 billion yrs

SDPAD1998
Luminosity: 1.7 Suns
Temperature: 6,100 K
Lifetime: 10 billion yrs

KLCL2020
Luminosity: 2 Suns
Temperature: 6,000 K
Lifetime: 10 billion yrs

PRIVERS3000
Luminosity: 0.6 Suns
Temperature: 6,100 K
Lifetime: 10 billion yrs

BNK437456
Luminosity: 1 Suns
Temperature: 5,900 K
Lifetime: 10 billion yrs

MED2005
Luminosity: 2.3 Suns
Temperature: 5,800 K
Lifetime: 10 billion yrs

G143
Luminosity: 1.6 Suns
Temperature: 6,200 K
Lifetime: 10 billion yrs

Beta Sagittae
Luminosity: 300 Suns
Temperature: 6,000 K

Krugar 608
Luminosity: 0.00008
Suns
Temperature: 3,100 K
Lifetime: 100 billion
yrs

TGWN1994
Luminosity: 2 Suns
Temperature: 6,000 K
Lifetime: 100 billion
yrs

KSTAR50
Luminosity: 0.01 Suns
Temperature: 3,500 K
Lifetime: 10 billion yrs

JS900
Luminosity: 0.06 Suns
Temperature: 4,200 K
Lifetime: 100 billion
yrs

DKAS118
Luminosity: 0.09 Suns
Temperature: 4,200 K
Lifetime: 100 billion
yrs

Epsilom Eri
Luminosity: 0.28 Suns
Temperature: 4,200 K
Lifetime: 10 billion yrs

Barnard S
Luminosity: 0.0003
Suns
Temperature: 3,000 K
Lifetime: 100 billion
yrs

NV2014
Luminosity: 0.5 Suns
Temperature: 5,200 K

DR85
Luminosity: 0.02 Suns
Temperature: 4,100 K
Lifetime: 10 billion yrs

EWBT2020
Luminosity: 0.09 Suns
Temperature: 4,200 K
Lifetime: 100 billion yrs

MJC2017
Luminosity: 0.04 Suns
Temperature: 3,800 K
Lifetime: 100 billion yrs

MW7
Luminosity: 0.03 Suns
Temperature: 4,800 K
Lifetime: 10 billion yrs

JENK413
Luminosity: 0.04 Suns
Temperature: 4,300 K
Lifetime: 100 billion yrs

COL2022
Luminosity:0.07 Suns
Temperature: 4,100 K
Lifetime: 100 billion yrs

Mu Geminorum
Luminosity: 310 Suns
Temperature: 3,100 K

BKBS456
Luminosity: 0.0006 Suns
Temperature: 3,100 K
Lifetime: 100 billion yrs

KLM453
Luminosity: 0.009 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

DS1977
Luminosity: 0.0001 Suns
Temperature: 3,100 K
Lifetime: 100 billion yrs

MS2011
Luminosity: 0.005 Suns
Temperature: 3,500 K
Lifetime: 100 billion yrs

LS2014
Luminosity: 0.0004 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

MJ1947
Luminosity: 0.03 Suns
Temperature: 3,600 K
Lifetime: 10 billion yrs

DALM1979
Luminosity: 0.0001 Suns
Temperature: 3,200 K
Lifetime: 100 billion yrs

HALA2011
Luminosity: 0.00005 Suns
Temperature: 3,000 K
Lifetime: 10 billion yrs

DCW5
Luminosity: 0.0005 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

OLPH1986
Luminosity: 0.0002 Suns
Temperature: 2,900 K
Lifetime: 100 billion yrs

LKSH13131
Luminosity: 0.0005 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

Acamar
Luminosity: 110 Suns
Temperature: 20,000 K
Lifetime: 1 million yrs

GP437
Luminosity: 22 Suns
Temperature: 9,900 K
Lifetime: 1 billion yrs

Ross 128
Luminosity: 0.0003 Suns
Temperature: 3,200 K
Lifetime: 100 billion yrs

Ross 614
Luminosity: 0.00007 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

Hassaleh
Luminosity: 3 Suns
Temperature: 8,300 K
Lifetime: 1 billion yrs

Phaet
Luminosity: 480 Suns
Temperature: 20,000 K
Lifetime: 100 million yrs

Ross 248
Luminosity: 0.0004 Suns
Temperature: 3,000 K
Lifetime: 100 billion yrs

Betelgeuse
Luminosity: 9,000 Suns
Temperature: 3,000 K

Sirius
Luminosity: 23 Suns
Temperature: 9,800 K

TMC1990
Luminosity: 0.001 Suns
Temperature: 11,400 K

GKS6866
Luminosity: 29 Suns
Temperature: 9,400 K
Lifetime: 1 billion yrs

Mirach
Luminosity: 480 Suns
Temperature: 3,200 K

SDSU1999
Luminosity: 81 Suns
Temperature: 26,000 K
Lifetime: 10 million yrs

Arneb
Luminosity: 10,000 Suns
Temperature: 7,300 K

XT702
Luminosity: 19 Suns
Temperature: 9,200 K
Lifetime: 1 billion yrs

Alpheratz
Luminosity: 132 Suns
Temperature: 22,000 K
Lifetime: 1 million yrs

Procyon
Luminosity: 8 Suns
Temperature: 8,600 K
Lifetime: 1 billion yrs

Castor
Luminosity: 19 Suns
Temperature: 9,800 K

Ruchba
Luminosity: 70 Suns
Temperature: 15,000 K
Lifetime: 10 million yrs

Wezen
Luminosity: 60,000 Suns
Temperature: 6,000 K

HN1200
Luminosity: 0.0002 Suns
Temperature: 10,200 K

PK222
Luminosity: 25 Suns
Temperature: 14,000 K
Lifetime: 100 million yrs

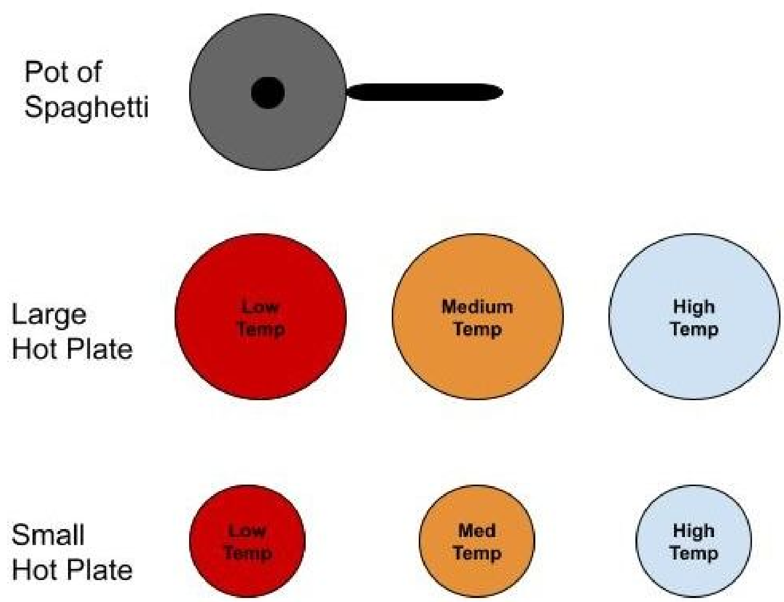
KOC99
Luminosity: 90 Suns
Temperature: 22,000 K
Lifetime: 10 million yrs

Mintaka
Luminosity: 10,000 Suns
Temperature: 40,000 K
Lifetime: 10 thousand yrs

Why do some stars not fall in the main trend line?

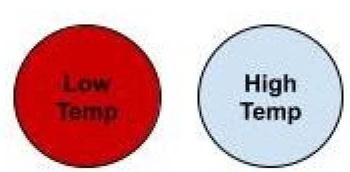
Why do some stars not fall in the main trend line?

Luminosity, Temperature and Size
Imagine you are comparing the abilities of electric hot plates of different sizes and temperatures to fully cook two identical large pots of spaghetti. Note that the pots are all as large as the largest hot plate.
The shading of each hot plate is used to illustrate its temperature.

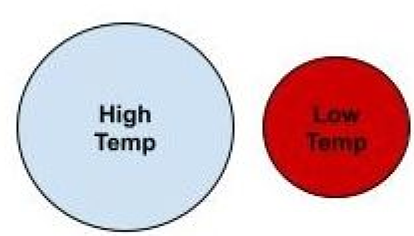


1. For each pair of hot plates shown below, circle the one that will cook the large pot of spaghetti more quickly. If there is no way to tell, state that explicitly.

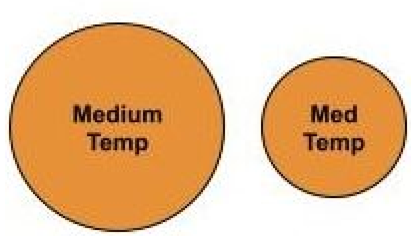
A)



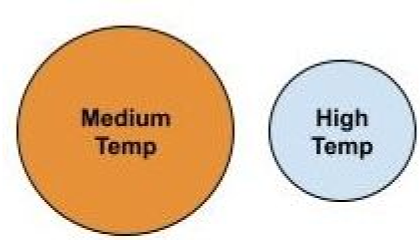
C)



B)



D)



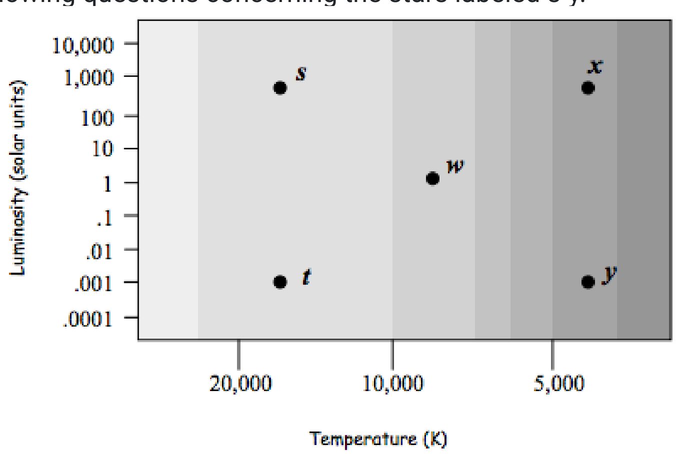
2. If you use two hot plates of the same size, can you assume that the hot plate that can cook a large pot of spaghetti first is at the higher temperature? Which lettered example above supports your answer?

3. If you use two hot plates at the same temperature, can you assume that the hot plate that can cook a large pot of spaghetti first is larger? Which lettered example above supports your answer?

4. If you use two hot plates of different sizes, can you assume that the hot plate that can cook a large pot of spaghetti first is at a higher temperature? Which lettered example above supports your answer?

Application to the H-R Diagram

The graph below plots the luminosity of a star on the vertical axis against the star's surface temperature on the horizontal axis. This type of graph is called an H-R Diagram. Use the H-R Diagram below and the relationship between a star's luminosity, temperature and size (as described on the previous page) to answer the following questions concerning the stars labeled s-y.



1. Stars s and t have the same surface temperature. Given that Star s is actually much more luminous than Star t, what can you conclude about the size of Star s compared to Star t? Explain your reasoning.

2. Star s has a greater surface temperature than Star x. Given that Star x is actually just as luminous as Star s, what can you conclude about the size of Star x compared to Star s? Explain your reasoning.

3. Based on the information presented in the H-R Diagram, which star is larger, x or y? Explain your reasoning.

4. Based on the information presented in the H-R Diagram, which star is larger, y or t? Explain your reasoning.

5. On the H-R Diagram, draw a “z” at the position of a star smaller in size than Star w but with the same luminosity. Explain your reasoning.

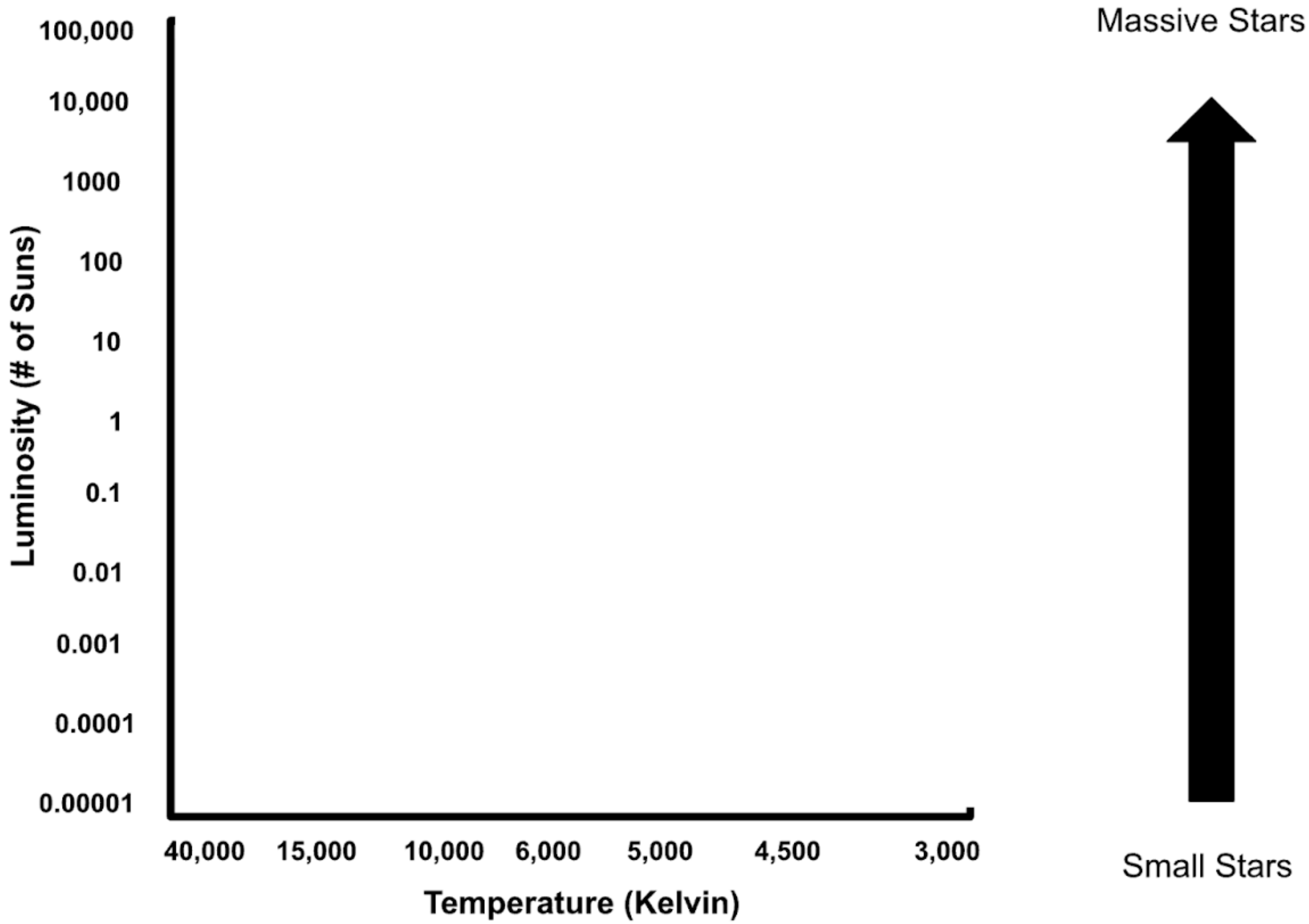
6. Betelgeuse is a star that has a temperature of 3000 K, but yet its luminosity of 9000 Suns is much higher than other 3000 K stars on the main trend line. Based on what you have just learned, what might explain this?

7. The star LP033276 has a temperature of 11,100 K, but yet its luminosity of 0.0001 Suns is much lower than other 11,100 K stars on the main trend line. What might explain this?

8. In what direction does the size of the star increase on the HR-Diagram you created? Indicate this increase in size on the right side of your HR-Diagram.

HR Diagram Graph Template

Poster Template - Creating a Mathematical Model to Compare Stars



Blank Star Circles

Use this master to create stars for the graphing activity.

Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______
Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______
Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______	Name: ____________ Luminosity: ________ Temperature: _______ Lifetime: _______

Planets and Orbits 5E	Is the exoplanet like Earth in terms of its distance from its star? What are the factors that allow an exoplanet to maintain a stable temperature?	**Performance Expectations** HS-ESS1-4	**Investigative Phenomenon** Comet Borrelly has water that is frozen most of the time, but every several years it shoots out a jet of vaporized water and dust.	**Time** 7-9 days

In this 5E instructional sequence, students are investigating the following questions that surfaced during the Driving Question Board launch - *Does the planet have the right temperature to sustain life? Does the Planet have liquid water?* This leads to questions about whether the average distance between a star and an exoplanet allows for the possibility of liquid water's existence throughout a period of revolution. Through graphical and algebraic analysis and interpretation of data, students investigate the orbits of planets and objects in our solar system. Through this exploration they determine relationships among orbital variables that are represented by Kepler's Laws. Students then apply what they have learned about orbits and habitable zones to exoplanet data and argue from evidence about which planet is most likely to maintain a temperature that allows for the existence of liquid water throughout a revolution around its star.

ENGAGE	Why does water on Comet Borrelly change from ice to vapor every 6 years?	Students **develop** an initial solar system **model** to show how characteristics of **orbits** might explain the phenomenon of phase change during a comet's revolution around the Sun and **generate questions** about what data they would like to investigate.
EXPLORE 1	Identifying patterns in solar system data to test their initial models	Students are provided with **orbital data** from our solar system and **graph it in order to identify evidence of patterns** and test their **explanatory models** for phase change and stability of water on Comet Borrelly and other objects that orbit the Sun.
EXPLAIN 1	Revising solar system models	Students use the **evidence of patterns identified in graphs** they created to **revise their solar system models** that explain water's phase change and stability on objects orbiting the Sun. They use their models to identify important **features of the motions of orbiting objects** that would allow a planet to maintain liquid water.
EXPLORE 2	Developing a mathematical model for solar system orbits	Students **use algebraic thinking to examine graphs** from the Explore 1 in order to **create a mathematical representation** that **allows them to identify the exact pattern** in the relationship between **orbital period** and **average distance between a planet/object and its star**.
EXPLAIN 2	Using a mathematical representation to determine the orbit of exoplanets	Students **use a mathematical equation** representing the **relationship between orbital semi major axis and orbital period (Kepler's Third Law)** to **make predictions** about exoplanets' **orbital semi major axis** based on each exoplanet's **orbital period**.
ELABORATE	Constructing orbits of exoplanets to determine whether liquid water can exist on each planet	Students **use a mathematical model** (**Kepler's First Law**) to **describe the relationship** between **orbital eccentricity, major axis, and distance between foci** of a **planet/object revolving around its host star**. Students then **use the mathematical model** and **algebraic thinking** to construct exoplanet orbits, allowing them to **make predictions** about which exoplanets stay within the habitable zone of their stars throughout an entire orbit.
EVALUATE	Developing or revising models to include new ideas about orbits	Students **develop new models or revise existing ones** to represent the idea that **stable** temperatures and the maintenance of liquid water result from **features of the motions of orbiting objects**.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

Why does water on Comet Borrelly change from ice to vapor every 6 years?

Students **develop** an initial solar system **model** to show how characteristics of **orbits** might explain the phenomenon of phase change during a comet's revolution around the Sun and **generate questions** about what data they would like to investigate.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Independent ❑ Small group	❑ Rumors	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ Which parts of the solar system have liquid water?	None	❑ Sticky notes ❑ Comet Borrelly Flyby

Launch

1. Remind students that, during the Driving Question Board launch, one category of questions that emerged was related to the temperature and the existence of liquid water on the exoplanets (for example, *Does the planet have the right temperature to sustain life? Does the Planet have liquid water?*).

2. Point out to students that the exoplanet data does not tell them whether water exists on the planets because so far our technology only allows us to detect the existence of water within our own solar system. Ask students: "How can we use what we know about water in our solar system to make claims about the potential for liquid water on exoplanets?" Students may propose to investigate the places where liquid water exists in our solar system and why it exists in these places.

3. Introduce the handout *Which parts of the solar system have liquid water?,* which provides some examples of planets and other objects in our solar system that have water in its different phases (ice, liquid, and vapor).

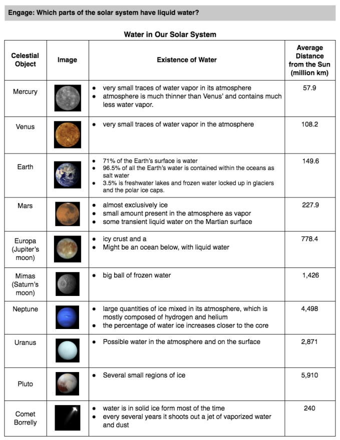
4. Show students a video of Comet Borrelly, to get them thinking about how the comet is different from other objects in the solar system.

Implementation Tip

The performance task for this unit asks students to develop a model of what makes Earth a place where life can exist, as a way to make claims about the habitability of exoplanets. If students don't suggest to investigate water in our solar system in order to make claims about water on exoplanets, refer back to the performance task prompt as a way to support them in arriving at the idea that we should study water in our solar system in order to make claims about water in other solar systems.

Surfacing Student Ideas

1. Have students read the *Water in Our solar system* table independently and use the **text annotation** strategy to identify 3-5 details they think are important to telling the story of the phenomenon of water in our solar system.



Engage: Which parts of the solar system have liquid water?

Water in Our Solar System

Celestial Object	Image	Existence of Water	Average Distance from the Sun (million km)
Mercury		• very small traces of water vapor in its atmosphere • atmosphere is much thinner than Venus' and contains much less water vapor.	57.9
Venus		• very small traces of water vapor in the atmosphere	108.2
Earth		• 71% of the Earth's surface is water • 96.5% of all the Earth's water is contained within the oceans as salt water • 3.5% is freshwater lakes and frozen water locked up in glaciers and the polar ice caps.	149.6
Mars		• almost exclusively ice • small amount present in the atmosphere as vapor • some transient liquid water on the Martian surface	227.9
Europa (Jupiter's moon)		• icy crust and a • Might be an ocean below, with liquid water	778.4
Mimas (Saturn's moon)		• big ball of frozen water	1,426
Neptune		• large quantities of ice mixed in its atmosphere, which is mostly composed of hydrogen and helium • the percentage of water ice increases closer to the core	4,498
Uranus		• Possible water in the atmosphere and on the surface	2,871
Pluto		• Several small regions of ice	5,910
Comet Borrelly		• water is in solid ice form most of the time • every several years it shoots out a jet of vaporized water and dust	240

Access for All Learners

While all students have some background knowledge on the topic of water existing in and changing into different phases, it's likely that most of them have never thought about this within the context of our solar system. Asking students to think about a similar phenomenon they are familiar with will help them connect to and find relevance in ideas about energy they already know. This will help all students generate initial ideas about why water exists in different phases on different objects in our solar system and why it changes phase on Comet Borrelly.

Differentiation Point

The *Water in Our solar system* data table may be overwhelming for some students at first. Students who need more support can start with a smaller set of data (just Mercury, Earth, Jupter, and Comet Borelly, for example). The teacher can also guide the text annotation work by asking questions like the following:

- Which planets are closest to and farthest from the Sun?
- What does "average distance" mean?
- What are all the forms of water that are named in the middle column?

2. Support students' thinking about the table by asking the following questions:
    a. Why do you think the large majority of water on Earth exists as liquid, but most if not all water on other solar system objects in the table exists as ice or vapor?
    b. What might explain the fact that Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust?

3. Have students work in small groups to share the important details they underlined, then write a description of the phenomenon.

Implementation Tip

Make sure that students understand what "average distance" means in this table, without giving away the point that they will be figuring out in this 5E lesson, which is that comets have a low average distance from the Sun because they spend part of their orbit very far away, and part of it very close by.

Describe the phenomenon
Talk with your group and tell the story of the phenomenon captured in the video and the *Water in the solar system* table.

The large majority of water on Earth exists as liquid, but most if not all water on other solar system objects in the table exists as ice or vapor.

Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust.

4. Have students turn to a partner and discuss the following prompt about related phenomena: *What other phenomena are you familiar with that are associated with water in different places existing in different phases?*
5. Ask students to independently develop an initial model that explains the phenomenon.
6. Have each student write a response to the question: *What might explain the fact that Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust?* on a sticky note.
7. Use the Group Learning Routine **Rumors** to have all students share their initial ideas with each other.
8. After students have shared their ideas through Rumors, categorize student ideas in order to address during the instructional sequence. Students are likely to have a range of ideas.

Routine

Rumors is a routine designed to surface all students' initial ideas in a low stakes manner. After having an opportunity to independently brainstorm, students identify the idea they are most confident about and share it with several classmates. Students listen for trends in their thinking and at the end of the routine share those trends with the rest of the class including the teacher. Please read the Earth & Space Science Course Guide for detailed steps about this routine.

Access for All Learners

All students have some background knowledge about why water exists in different phases, and this Engage phase is designed to support students in applying their existing intuitions to making sense of solar system data. Incomplete ideas are evidence of sensemaking, and there will be plenty of opportunities for students to develop an accurate explanation of Comet Borrelly's behavior.

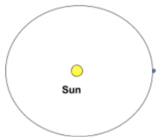
Classroom Supports

Create a poster or space on a whiteboard for categories of student ideas that have come up. Use the title *Water in Our solar system.* Use this tracking tool to return to ideas in the unit.

Develop an initial model

Use the diagram below to create an initial model explaining the phenomenon.

- Include data to support your model.
- Annotate your model, so it clearly explains the phenomenon.



Look & Listen For

Students have background knowledge that can be used to drive the investigation. Listen for the following ideas related to energy and its conservation that students grappled with in middle school:

- Somehow the Sun is transferring more electromagnetic energy to Comet Borrelly every several years, increasing the average kinetic energy (temperature) of water molecules enough for them to vaporize (MS-PS1.A, MS-PS3.A, MS.PS4.B)
  - *Students will be able to confirm this idea when they analyze and interpret the solar system Orbital Data table in the Explore 1 phase.*
- Maybe the electromagnetic waves from the Sun hit water on the comet with more intensity every several years because it's its tilt with respect to the earth changes, like seasons on Earth (MS.ESS1.B, MS.PS4.B)
  - *When students analyze and interpret the solar system Orbital Data table in the Explore 1 phase, they will find no evidence that comet Borrelly experiences seasons because of a tilted access like Earth. They will instead find that the distance at which the comet orbits around the sun decreases significantly during its orbit, which could easily account for the phase change of water every six years.*

9. Tell students that the class will need to investigate further in order to test their ideas about why Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust.

10. Ask students to independently generate at least 3 questions they want to investigate further in order to explain the Comet Borrelly phenomenon. Have them turn to a partner and take turns sharing questions, then decide which two questions they want to share with the rest of the class.

Look & Listen For

Students may surface these questions that are relevant to this phenomenon and can be used to transition to analyzing solar system orbital data in the Explore phase:

- At what distance does Comet Borrelly orbit our Sun during different points of its orbit?
- What is Comet Borrelly's orbit like? What are its characteristics?
- How is Comet Borrelly's orbit different from orbits of other objects in the solar system?
- What patterns do we see in the orbits of objects with water in solid phase? Gas? Liquid?

Differentiation Point

If students are able to demonstrate a complete understanding of why water exists in different phases on different celestial objects in our solar system and why water changes phases on Comet Borrelly, consider having them skip the Explore 1 and Explain 1 phases, which support the development of those explanations. If you have students skip the Explore 1 and Explain 1 phases, graphing of orbital variables still needs to be completed prior to the Explore 2 phase.

Explore 1

Identifying patterns in solar system data to test their initial models

Students are provided with **orbital data** from our solar system and **graph it in order to identify evidence of patterns** and test their **explanatory models** for phase change and stability of water on Comet Borrelly and other objects that orbit the Sun.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Groups of 2-3 Students	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ What are orbits like in our solar system?	None	❏ Computers with Excel or Google Sheets ❏ Excel Spreadsheet for Planet Data Analysis Graphing ❏ *What are orbits like in our solar system? Student Work*

Launch

1. Remind students that, at the end of the Engage phase, they surfaced the idea that they need to investigate the distance Comet Borrelly is from our Sun and the characteristics of Comet Borrelly's orbit.

2. Tell them that they will be looking for evidence of patterns in orbital data from our solar system in order to make sense of the phase changes of water on Comet Borrelly.

Analyzing data about objects in the solar system

1. Provide each student with the handout *What are orbits like in our solar system?*

2. Ask students what they think they should look for in the data in order to better understand the water in the solar system phenomenon. Listen for students to say they want to look for evidence of patterns and leverage that to move to step 3.

3. Ask students to turn and talk to a partner and discuss the following question:
    - What have you done in the past to represent data in a way that makes it easier to identify evidence of patterns?

Students will probably offer the ideas of "creating a graph" and "looking for trends." If they don't prompt them to think about what they did with the Star Circle data in order to identify evidence of patterns. Once students have said they want to graph the orbital data use that transition to step 4.

4. Provide students with computers that have a spreadsheet application like Excel or Google Sheets.

5. Support students in making decisions about what data they would like to graph by encouraging them to look for possible patterns/relationships they would like to confirm or see more clearly by graphing the data.

6. As students complete their graphs and make interpretations, confer with them to support their sensemaking.

Implementation Tip

If students have never used Sheets or Excel to create graphs, it may be necessary to take time out for a tutorial at this point. It is important that students create and analyze graphs independently, as this is how they develop the practice of modeling.

Integrating Three Dimensions

Students have had multiple opportunities to consider **CCC #1 - Patterns** so far in this unit**.** In this phase, the idea that graphs and charts are useful for identifying patterns in data is an important middle school element of the CCC. Prompt students to think about how they can represent the data in order to more easily identify evidence of patterns. This will make it easier to foreground this element of Patterns at the end of this phase and build toward an important high school element of patterns during the Explore 2 and Explain 2 phases.

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 Earth & Space Science Course Guide for support with this routine.

Explore 1: What are orbits like in our solar system?

Examine and graph the *Solar System Orbital Data* below, **looking for evidence of patterns** that might help you form a claim about why water exists in different phases on different objects in the Solar System.

Solar System Orbital Data

Celestial Object	Average Distance from the Sun[1] (AU)	Period of Revolution (Earth years)	Minimum Distance from Sun	Maximum Distance from Sun	Phase of majority of water
Mercury	.387	.241	0.307	0.467	vapor
Venus	.723	.615	0.718	0.728	vapor
Earth	1.00	1	0.983	1.017	liquid
Mars	1.523	1.88	1.381	1.666	ice
Comet Borrelly	3.590	6.80	1.350	5.830	Ice, but a great deal vaporizes every several years
Europa (Jupiter's moon)	5.203	11.87	4.950	5.459	Ice layer at surface, with liquid water ocean underneath
Mimas (Saturn's moon)	9.539	29.46	9.041	10.124	
Uranus	19.185	84.03	18.324	20.078	ice
Neptune	30.061	164.82	29.709	30.386	ice
Pluto	39.479	248.06	29.658	49.304	ice

1 Note: One AU is equivalent Earth's average distance from the Sun.

Conferring Prompts

Confer with students as they work in collaborative groups to complete the graphs.
Suggested conferring questions:

- What data do you think is most relevant to explaining why water exists in different phases on different celestial objects and why water on Comet Borrelly changes phases during its orbit?
- What patterns do you see in the solar system orbital data that could help you explain the Comet Borrelly investigative phenomenon?

Explore 1: What are orbits like in our solar system?

See-Think-Wonder

See	Think	Wonder
A pattern I noticed:		
A pattern I noticed:		
A pattern I noticed:		
A pattern someone in my group noticed:		
A pattern someone in another group noticed:		

1. After students have had an opportunity to analyze and interpret the data, have them independently complete the See-Think-Wonder organizer.

Conferring Prompts

TIP: Confer with students as they work in collaborative groups to analyze 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):

- What patterns do you see in the relationship between the phase of water on solar system objects and their average distance from the Sun?
- What pattern do you see in the minimum and maximum distance from the Sun?
- What patterns do you see in the relationship between an object's average distance from the Sun and orbital period?
- Do all objects in the solar system fit that pattern?
- Which patterns or exceptions to patterns in the data that could help us explain the Comet Borrelly investigative phenomenon?

2. Elicit student ideas through the group learning routine, **Domino Discover.**

Look & Listen For

There are several patterns students may see in the solar system orbital data that could help you explain the Comet Borrelly investigative phenomenon. Some possible responses that show students are making sense of the include these responses to the See-Think-Wonder

See

- The planets and objects that have water in solid ice form are further from our Sun than Earth, where water is mostly liquid
- The planets and objects that have water in vapor/gas form are closer to our Sun than Earth
- The distance at which Comet Borrelly and Pluto revolve around the Sun changes a lot compared to other planets and objects in the solar system
- As the average distance at which an object orbits around the Sun increases, so does the orbital period

Think

- I think this is because the further away you get from our sun, the colder it is, so water is frozen
- I think this is because the closer you get to the sun, the hotter it is, so water is in vapor form
- Earth is at just the right temperature for most of our water to exist in liquid form
- I think this might be the reason Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust
- I think this is because if a celestial object orbits further away, its orbit is longer so it takes longer

Wonder

- Do the planets that have water in mostly ice and vapor form have any liquid water? Did they ever?
- Does comet Borrelly ever have water in liquid form?
- Do the exoplanets we're investigating orbit around their stars at a distance that allows water to be in liquid form? Do they stay at that distance throughout their entire orbit around their star?

Implementation Tip

At this point it's ok if students only name the distance a planet travels as a factor that contributes to the relationship between average distance from the Sun and orbital period. An understanding of the role gravity plays in determining this relationship will be developed in Unit 2 of this course.

3) If students don't surface one or more of the observations above, display student graphs and use the suggested conferring questions from this Explore 1 phase to have students surface those ideas. Then ask students to share their thoughts about whether any of the newly surfaced patterns are relevant to our questions regarding water existing in different phases on different objects in our solar system.

Differentiation Point

Some students may have difficulty identifying relevant patterns in the solar system orbital data. Differentiate for these students by including sentence starters in the ‘See’ column of the See-Think-Wonder organizer that support them in identifying those patterns.

Explain 1

Revising solar system models

Students use the **evidence of patterns identified in graphs** they created to **revise their solar system models** that explain water's phase change and stability on objects orbiting the Sun. They use their models to identify important **features of the motions of orbiting objects** that would allow a planet to maintain liquid water.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Groups of 2-3 Students	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Revising Solar System Models ❑ Summary Task	None	

Launch

1. Remind students that we are trying to figure out why water exists in different phases on different celestial objects and why water on Comet Borrelly changes phases during its orbit.
2. Tell students that they will now have an opportunity to use evidence of patterns in orbital data to revise their initial solar system models from the Engage phase.

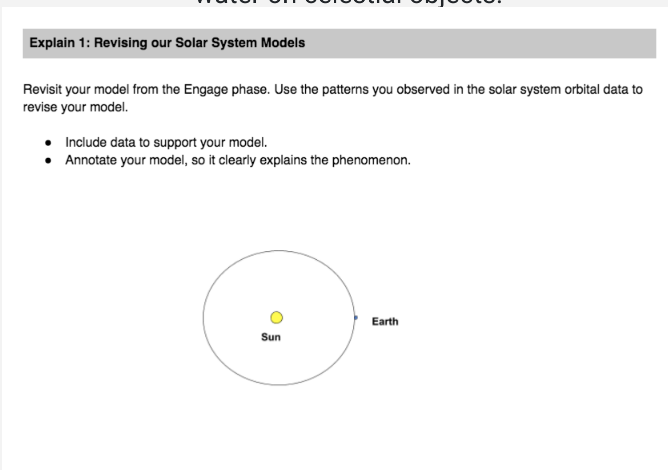
Revising Models

1. Have students work in small groups to revise their initial models.
2. Confer with groups as they work to understand how they are thinking about the phenomenon, and as a way to get a sense of the range of student ideas in the classroom.

Look & Listen For

As students are revising their models, look and listen for these ideas, which will be important to surface in the Class Consensus Discussion:

- Celestial objects on which water exists mostly as vapor orbit closer to the Sun than Earth.
- Celestial objects on which water exists mostly as ice orbit further from the Sun than Earth.
- Comet Borrelly and Pluto both have orbits that are more elliptical than the other orbits.
- Annotations that articulate how the orbits explain the most abundant phase of water on celestial objects.


Explain 1: Revising our Solar System Models

Revisit your model from the Engage phase. Use the patterns you observed in the solar system orbital data to revise your model.

- Include data to support your model.
- Annotate your model, so it clearly explains the phenomenon.

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 a few days ago, to learn about all the thinking in the room. This time we are going to come to some decisions about what explains the existence of water in different phases on different celestial objects in our solar system."

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

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. Call on the selected students to share their solar system models with the class. This should not be done randomly; it should be based on observations and conferring done as students were working. The point of this discussion is to elevate ideas that move the class towards greater understanding of the role orbits play in stability and change of planet temperature and the potential existence of liquid water. The decision about which models 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. (See the previous Look and Listen For for suggestions.)

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

4. With each group that presents, pause and reflect on the important features of the motions of orbiting objects that explain stability and change of temperature and phase of water on objects in our solar system.

Routine

Class Consensus Discussions provide an opportunity for groups to share out around their sensemaking and for other groups to list, summarize, and ask questions after each share.

We recommend you have groups display their data and models while they share their ideas. A discussion with no visual component can leave out a number of students.

Integrating Three Dimensions

The prompt about patterns in the Class Consensus Discussion are in support of students' consideration of **CCC #1 - Patterns.** They are asking students to reflect upon how a mathematical representation (graphs) was useful for identifying evidence of patterns. Be sure to assess whether students apply their understanding of the high school patterns element addressed in the How the Sun Works 5E. At this point they should name the specific empirical evidence they used to identify different patterns. If they do not, prompt them to do so.

5. Proceed through the steps in the Consensus Discussion Steps. 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, so be sure to facilitate the conversation so that key ideas emerge. The following prompts may help with surfacing key ideas through the lens of Stability and Change:
    - What patterns did you see in the orbital data? How did graphing the orbital data help you to identify evidence of these patterns?
    - What determines whether a planet or object's temperature is stable or unstable throughout its entire orbit?
    - What factors are causing the phase of water to change or stay the same?

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following **key points**. Note that the terms in bold are ones that students probably will figure out but not know the formal vocabulary work. It is appropriate to provide these terms at this point!

- Graphing the data provided a visual that made it much easier to see evidence of the patterns.
- Objects in our solar system orbit around the Sun at different distances and this has an effect on the temperature and phase of water on those objects.
- Most of the objects in our solar system have orbits that are very close to being circular, so they maintain a stable enough temperature for water to stay mostly in one phase throughout an entire revolution around the Sun.
- Some planets in the solar system exist in a **habitable zone**; when looking for exoplanets that can support life we should look for planets in that zone.

6. Have students talk to each other in groups and decide 1-3 things that should be in the class consensus model. Use the Group Learning Routine, **Domino Discover** to surface student ideas. Document these ideas where all students can see them.

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, after having made sense of an experience, which may be particularly helpful for **transitioning** language learners, who already have some mastery of language.

Summary

1. Ask students to work independently to complete the Summary Task.
2. Use the answers in the Summary Task to make decisions about which ideas may need to be revisited or explored more in coming parts of this 5E Instructional sequence.

Explain 1: Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

____

____

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today: ______________

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. How have we used patterns to develop an explanatory model for water's phase change and stability on objects orbiting the Sun?

Explore 2

Developing a mathematical model for solar system orbits

Students **use algebraic thinking to examine graphs** from the Explore 1 in order to **create a mathematical representation** that **allows them to identify the exact pattern** in the relationship between **orbital period** and **average distance between a planet/object and its star**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ How far are the exoplanets in our data set from their stars?	None	❑ Computers with Excel or Google spreadsheet ❑ Exoplanet Detection: the Transit Method Transit Method Different Planet Sizes Transmit Method Multiple Planets What's a Transit?

Launch

1. Explain that the next part of the investigation will address orbital patterns of exoplanets, and ask students for their thoughts on why we are moving from our solar system to looking at planets orbiting other stars.

2. Tell students that one of the ways exoplanets are detected is called the **transit method**, and while this method allows us to detect exoplanets and make some determinations about them, it does not allow us to collect data about the distance at which the exoplanets orbit from their star. Explain that students will be making sense of a computational model of the transit method in order to see if it provides data that is useful for determining characteristics of orbits.

Implementation Tip

The term **transit method** is not a key concept or piece of vocabulary for this unit. Rather, it is a shared tool students are going to be using. For that reason, it is fine to teach this as a term without exploration first.

Working with a Computational Model

1. Provide students with the NASA simulations Exoplanet Detection: the Transit Method , Transit Method Different Planet Sizes , and Transmit Method Multiple Planets . Have students work in pairs to use the simulation to look at different methods (single planet, different size planets, and multiple planets), with these guiding questions:
    - What patterns do you see in the simulation? What is your evidence?
    - What inferences can we make based on these patterns? Why?

1. As students work, confer with them to ensure they are trying all the possible ways of using the simulation and surfacing all the key points. Refer to the Look & Listen for points below.

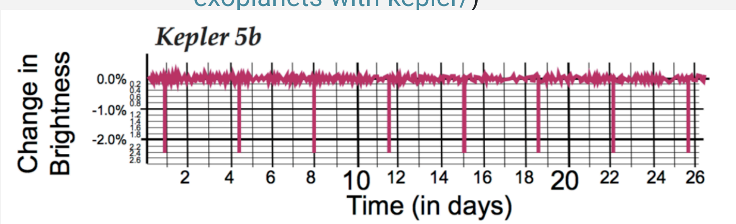
2. Project the NASA simulation on the board, and ask several pairs to share their findings. Be strategic in selecting students to share out, so that a range of ideas are surfaced.

Look & Listen For

- When the planet passes in front of its star or how often the planet passes in front of its star. We know this because the light from the star decreases the same amount each time a planet passes in front of it
- The relative size of the planets. We can figure this out by observing how much the light from the star decreases -- bigger planets make the light decrease more
- The number of planets orbiting around a star. We know this by watching to see if the light from the star decreases by different amounts

Listen especially for the key information below, which is required for success in the next phase

- The most important idea here is that the transit method allows us to determine how often a planet passes in front of a star.
    - If this idea does not surface, show students the transit method graph below. Ask them to approximate how often the brightness of this star decreases due to Kepler 5b passing in front of it (3.5 days). (This activity is available from NASA JPL at the following link: https://www.jpl.nasa.gov/edu/teach/activity/exploring-exoplanets-with-kepler/)



- After there is a shared understanding of this idea, students should be clear that the orbital variable that relates to this is **orbital period.** This is the variable they will work with in the next part of the Explore 2 phase.

Integrating Three Dimensions

The prompts about patterns support students' consideration use of **CCC #1 - Patterns.** Students should, at this point, be used to seeking out patterns as a way to make sense of simulations and data sets!

Access for Multilingual Learners

For **emerging language learners,** hearing from classmates describing the activity they just completed and their findings provides comprehensible input that supports their language development. It also gives **transitioning language learners** an opportunity to rehearse and try out ideas in front of the class, which is more supportive than extemporaneous talk or cold calling.

Analyzing Data about Orbital Motion

1. Provide students with some framing for analyzing data about orbital motion. As a way of narrating this transition, show some of the artifacts (graphs, verbal explanations, etc.) of ideas that have been figured out so far, and narrate the next step: "The transit method does not tell us anything about the distance at which exoplanets orbit around their star. We just figured out that the transit method shows there is something orbiting, but that's all! Remember in Explore 1 we observed a pattern in the relationship between average distance at which a celestial object orbits around the Sun and its orbital period? Let's go back and think about that relationship some more."

2. Display the graph and ask students to turn and talk to a partner about how they can use the evidence of a pattern in the graph to make claims about the average distance at which EXOPLANETS orbit from their respective stars.

3. Ask a few pairs to share out and listen for them to say that they can see at which average distance the exoplanet's orbital period intersects the graph. Acknowledge the idea and suggest that the class tries this method.

4. Ensure that all students have the graph accessible and ask them to discuss the following prompt in pairs:
    - If an exoplanet's orbital period is 50 Earth years, what is the avg distance at which it orbits its star?

5. Have several pairs share out and listen for a range of responses between 12.5 and 14 AUs. Ask students why there were a range of responses and why this might be a problem when predicting the average distance at which an exoplanet orbits from its host star. Listen for students to say that the graph makes it challenging to decide at exactly which average distance the orbital period intersects the graph and that would lead to less confidence in their claims.

6. Explain that a way scientists address this challenge is by representing patterns through equations we can derive from the data.

7. Have students revisit their spreadsheets (using Excel, Google Sheets, or another system) and derive an equation that describes the relationship between the average distance at which a celestial object orbits the Sun and its orbital period.

8. As groups are working, support them with figuring out the mathematical model equation. It may be that some pairs need more one-on-one support with using the spreadsheet to create a model. See the Tip box below with guidance on this.

9. Ensure that all groups have come up with an equation that represents the data.

10. Make a determination about whether to have groups share out or just move on. The share may be redundant if all groups are confident in their mathematical equation, and the teacher has determined the mathematical equation to be correct.

Integrating Three Dimensions

This is an opportunity to support students' use of **CCC #1 - Patterns** alongside **SEP #2 - Developing & Using Models.** Students have had multiple opportunities so far in this unit to seek out patterns as a way to make sense of simulations and data sets. Deriving a mathematical equation from data will support students in understanding the role mathematical representations play in allowing them to identify patterns that otherwise could not be identified. In this case allowing them to describe the pattern in the relationship between orbital period and average distance more accurately. They will explicitly reflect upon this in the Explain 2 phase.

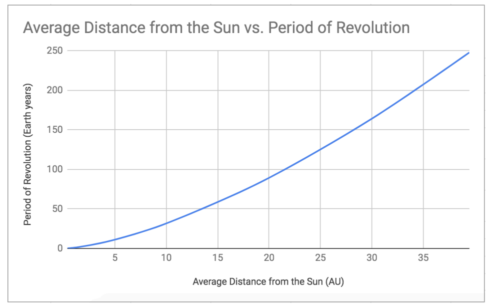
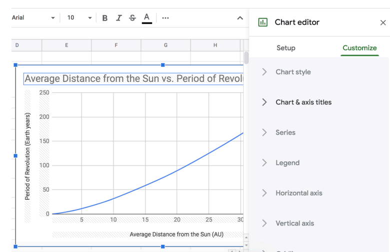
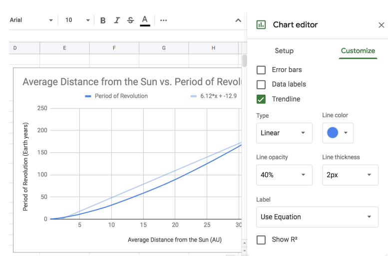
Implementation Tip

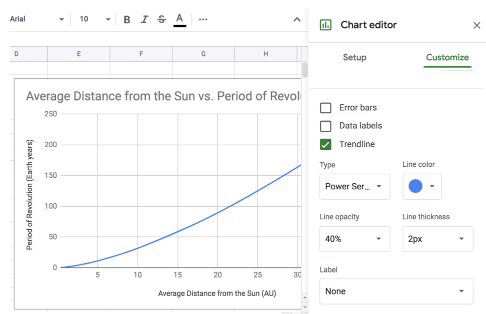
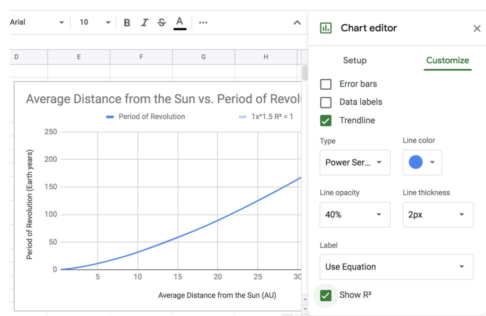
This is their first time deriving an equation as a mathematical representation. This activity, therefore, is more guided than subsequent ones may be. The goal here is to move students toward understanding the necessity of a mathematical representation (equation) for identifying some patterns in data by the end of the Explain 2 phase. At this point, they don't necessarily need to internalize the process for deriving the equation or understand the function that best fits the graph.

Implementation Tip

Since this may be students' first time using a spreadsheet to derive an equation from a data, consider facilitating this as a pair activity, with whole-class check-ins to make sure everyone is following the process.

The following are steps for deriving equations from data using Google Sheets:

Graph the data (average distance from the Sun vs period of revolution)	
Double click on the graph and select 'Series' from the menu on the right	
Click 'Trendline' on the bottom of the 'Series' menu	

Try the different types of trendlines until you find one that best fits the graph. 'Power Series' should be an exact fit.	
Click on the drop down for 'Label' and select 'Use Equation'. Then click on 'Show R^2'.	
The equation and R^2 value below should appear at the top of the graph. *X* = orbital period $X^{1/3}$ (cube root) = the average distance between the celestial object and its star, or semi-major axis. Note: In this image R does not represent average distance. An R^2 value of 1 indicates the trendline line chosen is a perfect fit for the graph.	1x^1.5 $R^2 = 1$

Explain 2

Using a mathematical representation to determine the orbit of exoplanets

Students **use a mathematical equation** representing the **relationship between orbital semi major axis and orbital period (Kepler's Third Law)** to **make predictions** about exoplanets' **orbital semi major axis** based on each exoplanet's **orbital period**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Class Consensus Model	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Kepler's Third Law ❑ Applying our mathematical model of orbits to exoplanets ❑ Summary Task	None	❑ Kepler's Third Law Calculator ❑ *Which Exoplanets Stay Within the Habitable Zone Example Class Response*

Launch

1. Frame the next activity for students: "Now that we have established a mathematical representation of the relationship between a planet's average distance from its host star and orbital period, how can we use that to make a claim about objects orbiting *other* stars?" Have students share their thinking about applying what we figured out to other stars in the universe.

2. Share with students that an astronomer named Johannes Kepler went through a similar process to the one they just did to derive mathematical equations like the ones they did. The whole point of coming up with these equations is being able to make predictions about other situations, where we don't have as much information.

3. Have students review the law and write the equation as a verbal explanation on the *Kepler's Third Law* handout. Ensure that students see the connection before moving on.

4. Point out that Kepler's equation had one other variable, the mass of the Sun. Ask students how we might account for stars with different masses. Explain that the mass of other stars will be provided in solar masses.

Explain 2: Kepler's Third Law

Kepler's Third Law of Planetary Motion

Mathematical Model	Period of revolution (Earth years) → ; Mass of the host star (solar masses) → $M_s \times T^2 = R^3$ ← Average distance from host star (AU)
Verbal Model	

Applying Mathematical Models to Exoplanets

1. Have students work in pairs to complete the *Applying our mathematical model of orbits to exoplanets* handout.

2. As students are working, consider which groups should share in the class consensus discussion in order to surface many viewpoints.

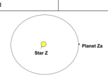
Explain 2: Applying our mathematical model of orbits to exoplanets

Part 1: Average distance vs orbital period: How can we apply our mathematical model?

1. Examine the orbital data below. Then complete the diagram by depicting where the orbits of Planet Zb, Planet Zc, and Planet Zd would lie with respect to Planet Za. Be sure to provide evidence and reasoning from the mathematical model above to support your claims.

Data on Objects Orbiting Star Z

Celestial Object	Period of Revolution (Earth years)
Planet Za	1.2
Planet Zb	3.5
Planet Zc	0.80
Planet Zd	1.8



2. Use the mathematical representation of the relationship between a planet's average distance from its host star and orbital period to calculate the data missing from the table.

Celestial Object	Mass of Host Star (solar masses)	Period of Revolution (Earth years)	Average Distance from Host Star (AU)
Planet Ya	.7	.58	
Planet Yb	6.5	1.45	

Explain 2: Applying our mathematical model of orbits to exoplanets

Part 2: What is the average distance between exoplanets in our data set and their host stars?

1. Use the mathematical model your class has derived to predict the average distance between each planet in our exoplanet data set and their host stars. You have already determined the orbital period for each exoplanet and the mass of their host stars have been provided by NASA.

Exoplanet Orbital Data

Exoplanet Name	Mass of Host Star (solar masses)	Period of Revolution (Earth years)	Average Distance from Host Star (AU)	Habitable Zone Inner Limit (AU)	Habitable Zone Outer Limit (AU)	Is it possible that this planet stays within the habitable zone?
Kepler-79 b	1.165	0.0369		1.711	4.229	
Kepler-36 b	1.071	0.0379		1.994	4.922	
Kepler-18 b	0.972	0.00962		1.463	3.227	
Kepler-186 f	0.544	0.356		0.242	0.464	
Kepler-432 b	1.35	0.1438		3.011	5.449	
HD 17156 - b	1.275	.05813		0.986	1.726	
HD-20782 b	1.43	1.605		2.613	4.632	
Trappist-1 b	0.089	0.00414		0.023	0.048	

1. Based on your calculations, which exoplanets travel within the habitable zone when they are at the average distance from its star? Be sure to cite evidence for your claim.

2. Does this mean that they orbit within the habitable zone throughout their orbital period of revolution around their host star? Why?

3. What other information would you like to have?

Integrating Three Dimensions

The prompts in the handout are designed to get students thinking about and using **CCC #1 - Patterns and CCC # 3 Scale, Proportion, and Quantity** to make sense of the analysis of these planets. The mathematical model that describes the pattern in the relationship between orbital period and average distance of celestial objects, can be used to predict the average distance at which exoplanets orbit around their stars which is an example of using algebraic thinking to examine scientific data and predict the effect of a change in one variable on another, an important element of **CCC # 3 Scale, Proportion, and Quantity.**

Look & Listen For

As students are completing their responses, look and listen for these ideas in response to the questions below, which will be important to surface in the Class Consensus Discussion:

1. The graph of orbital period vs semi major axis length allowed us to identify a pattern in the relationship between these two variables. How did our mathematical model (Kepler's Third Law) help us describe this pattern more accurately than the graph?

The graph only lets us see that as the average distance at which a planet orbits from its star increases, the orbital period increases too. The mathematical model let us see exactly how those variables relate to each other by including exponents.

2. Based on your calculations, which exoplanets travel within the habitable zone when they are at the average distance from its star? Be sure to cite evidence for your claim.

Kepler 186 f - when you plug its orbital period of 0.3556 years and its host star mass of 0.544 Sun masses into Kepler's 3rd law, I calculate that the average distance at which it orbits its host star is 0.4097 AU, which falls within the habitable zone of 0.242 - 0.464 AU.

Kepler 442 b - when you plug its orbital period of 0.3078 years and its host star mass of 0.61 Sun masses into Kepler's 3rd law, I calculate that the average distance at which it orbits its host star is 0.3866 AU, which falls within the habitable zone of 0.252 - 0.531 AU.

TOI-2257 b - when you plug its orbital period of 0.0964 years and its host star mass of 0.33 Sun masses into Kepler's 3rd law, I calculate that the average distance at which it orbits its host star is 0.1453 AU, which falls within the habitable zone of 0.079 - 0.167 AU.

Trappist 1f - when you plug its orbital period of 0.0252 years and its host star mass of 0.089 Sun masses into Kepler's 3rd law, I calculate that the average distance at which it orbits its host star is 0.0384 AU, which falls within the habitable zone of .023-.048 AU.

Trappist 1g - when you plug its orbital period of 0.034 years and its host star mass of 0.089 Sun masses into Kepler's 3rd law, I calculate that the average distance at which it orbits its host star is 0.0469 AU, which falls within the habitable zone of .023-.048 AU.

3. Does this mean that they orbit within the habitable zone throughout their orbital period of revolution around their host star? What other information would you like to have?

Not necessarily. Their orbits could be like Comet Borrelly. We still need to figure out their orbital shapes!

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 a few days ago, to learn about all the thinking in the room and come to some decisions about what our mathematical model has helped us figure out about the orbit, and the potential for water, on exoplanets in our data set." The share will be about responses to the following prompts from the *Explain 2: Applying our mathematical model of orbits to exoplanets* handout:

- The graph of orbital period vs semi major axis length allowed us to identify a pattern in the relationship between these two variables. How did our mathematical model (Kepler's Third Law) help us describe this pattern more accurately than the graph?
- Based on your calculations, which exoplanets travel within the habitable zone when they are at the average distance from their star? Be sure to cite evidence.
- Does this mean that they orbit within the habitable zone throughout their orbital period of revolution around their star? What other information would you like to have?

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

2. Select two or three groups' to share their responses 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 a mathematical model can be used to generate evidence to make a claim about stability and change of planet temperature and the potential existence of liquid water on planets in the exoplanet data set. The decision about which groups 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 group to share their responses. You can do this by:
    - Projecting using a document camera; OR
    - Copying their responses to be shared and passing them out to the class; OR
    - Taking a picture of responses and projecting them as slides.

4. With each group that presents, pause and reflect on the important features of the motions of orbiting objects that explain stability and change of temperature and phase of water on objects in our solar system.

5. Proceed through the steps in the Consensus Discussion Steps. 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, so be sure to facilitate the conversation so that key ideas emerge.

Implementation Tip

Class Consensus Discussions provide an opportunity for groups to share out around their sensemaking and for other groups to list, summarize, and ask questions after each share.

We recommend you have groups display their data and responses while they share their ideas. A discussion with no visual component can leave out a number of students.

Which exoplanets stay within the habitable zone throughout their orbit around their stars?

Kepler 186 - f
Kepler 442 - b
TOI-2257 b
Trappist 1 - f
Trappist 1 - g

All are within the habitable zone of their solar system when they are orbiting at their average distance from their star.

we don't know for sure if they stay within the habitable zone throughout an entire orbit because we don't know the max and min distance at which they orbit (we don't know the orbit shape)

we need to know the shape of their orbits or the min and max distance

Take Time for These Key Points

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

- While the graph of orbital period vs semi major axis length allowed us to identify a pattern in the relationship between these two variables, the mathematical model described this pattern more accurately because it included exponents and a coefficient of star mass.
- By plugging in the orbital period for each planet into our mathematical model, we were able to generate additional data, average distance from its star, for each planet.
- This data served as evidence to make a claim about whether each planet maintains a stable temperature that would allow liquid water to exist.
- Kepler 186 - f, Kepler 442 - b, TOI-2257 b, Trappist 1 - f, and Trappist 1 - g are all orbiting within the habitable zone when they are at their average distance from the Sun.
- We don't know for sure if they stay within the habitable zone throughout an entire orbit because we don't know the max and min distance at which they orbit (we don't know the orbit shape).
- We need to know the shape of their orbits or the min and max distance.

Revisiting What Counts as an Evidence-Based Claim

1. Ask students to share their current thinking about what we are trying to figure out (*Does the exoplanet have stable temperature and maintain liquid water?*).
2. Facilitate a class discussion around what constitutes an evidence-based claim using their common experiences during this most recent 5E as a reference.

What Counts as an Evidence-Based Claim?

You found information from a book or a reliable source.

The evidence comes from an experiment or investigation you did.
The claim is not just someone's opinion. Many scientists can agree on that interpretation.
Patterns in data count as evidence you can use for claims.

Patterns in data can count as evidence for a claim. But you have to have evidence for the pattern too.

Evidence for a claim comes from other scientists' data.

Evidence for a claim comes from patterns observed in models based on data.

A model based on evidence, like a diagram that shows how something works.

we can use technology like a spreadsheet to derive mathematical models that allow us to generate data.

Data generated from a mathematical model can serve as evidence for making claims or predictions.

Sometimes you need two pieces of data together in order for either to serve as evidence.

Summary

1. Ask students to work independently to complete the Summary Task.

2. Use the answers in the Summary Task to make decisions about which ideas may need to be revisited or explored more in upcoming parts of this lesson.

Explain 2: Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today: ______________

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. How have we used *patterns* to develop and use a mathematical model that describes the relationship between orbital semi major axis and orbital period?

6. How did our mathematical models help us to make predictions about stability and change on exoplanets?

Elaborate

Constructing orbits of exoplanets to determine whether liquid water can exist on each planet

Students **use a mathematical model** (**Kepler's First Law**) to **describe the relationship** between **orbital eccentricity, major axis, and distance between foci** of a **planet/object revolving around its host star**. Students then **use the mathematical model** and **algebraic thinking** to construct exoplanet orbits, allowing them to **make predictions** about which exoplanets stay within the habitable zone of their stars throughout an entire orbit.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	❑ Think-Talk-Open Exchange	❑ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❑ How do we determine shapes of orbits? ❑ Which exoplanets orbit in the habitable zone?	None	❑ Classroom Demonstration: Elliptical Orbits

Launch

1. Frame for students where we are in figuring things out: Which exoplanets in the performance task data set stay within the habitable zone throughout an entire orbit? Tell them that the only exoplanet orbital data they have access to is the orbital period and the average distance at which each exoplanet orbits around its star, which they calculated using the mathematical model they developed.

2. Ask students to think about what they have done so far in this 5E investigation and brainstorm ideas for how we can figure out whether the exoplanets stay within the habitable zone throughout an orbit.

Look & Listen For

While pairs are sharing their responses, listen for these ideas, to provide a bridge to the Elaborate phase:

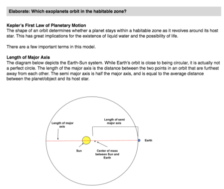
- We can find a relationship between the variables we know and the variables we are trying to figure out so we can develop a mathematical model
- We can use the mathematical model to calculate the variables we are trying to figure out and maybe use this data as evidence for a claim

3. Leverage the ideas above to transition to the next part of this phase, focused on Kepler's First Law.

Reading about Kepler's Law

1. Tell students that Johannes Kepler also developed a mathematical model that describes the relationship between the distance at which a planet orbits, the mass of objects in the solar system, and the shape of the planet's orbit. "While we have been able to determine which exoplanets in our data set are within the habitable zone when they are at their average distance from their host stars, we still need to determine whether they stay within the habitable zone throughout an entire revolution. Thankfully, Johannes Kepler also developed a mathematical model to describe and calculate orbital shapes."

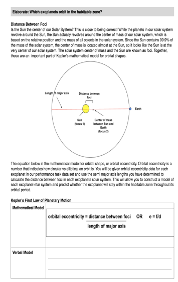
2. Have students read the text about Kepler's First Law of Planetary Motion, using a **text annotation** strategy to identify new ideas and ideas that are relevant to what we are trying to figure out.


Elaborate: Which exoplanets orbit in the habitable zone?

Kepler's First Law of Planetary Motion
The shape of an orbit determines whether a planet stays within a habitable zone as it revolves around its host star. This has great implications for the existence of liquid water and the possibility of life.

There are a few important terms in this model.

Length of Major Axis
The diagram below depicts the Earth-Sun system. While Earth's orbit is close to being circular, it is actually not a perfect circle. The length of the major axis is the distance between the two points in an orbit that are furthest away from each other. The semi major axis is half the major axis, and is equal to the average distance between the planet/object and its host star.


Elaborate: Which exoplanets orbit in the habitable zone?

Distance Between Foci
Is the Sun the center of our Solar System? This is close to being correct! While the planets in our solar system revolve around the Sun, the Sun actually revolves around the center of mass of our solar system, which is based on the relative position and the mass of all objects in the solar system. Since the Sun contains 99.9% of the mass of the solar system, the center of mass is located almost at the Sun, so it looks like the Sun is at the very center of our solar system. The solar system center of mass and the Sun are known as foci. Together, these are an important part of Kepler's mathematical model for orbital shapes.

The equation below is the mathematical model for orbital shape, or orbital eccentricity. Orbital eccentricity is a number that indicates how circular vs elliptical an orbit is. You will be given orbital eccentricity data for each exoplanet in our performance task data set and use the semi major axis lengths you have determined to calculate the distance between foci in each exoplanets solar system. This will allow you to construct a model of each exoplanet-star system and predict whether the exoplanet will stay within the habitable zone throughout its orbital period.

Kepler's First Law of Planetary Motion

Mathematical Model	$\text{orbital eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}}$ OR $e = f/d$
Verbal Model	

Differentiation Point

These two pages of the student materials include particularly dense text and introduce several tier three vocabulary terms. Consider providing small group instruction to **multilingual learners** and **below grade-level readers**. You can support them in navigating the text, by conducting a read aloud and prompting them to make connections between the written text being read aloud, diagrams, and the algebraic equation.

Constructing an Orbit

1. Put students into groups of three to work on calculating the distance between foci in each exoplanet's solar system and construct exoplanet orbits. Using Earth as an example, demonstrate how to construct an orbit. For teacher guidance around constructing orbits, watch the Classroom Demonstrations - Elliptical Orbits video. Have students follow along for practice while you:
    - Calculate the distance between foci based on the length of Earth's major axis and eccentricity
    - Use the distance between foci and the length of the major axis (length of string loop) to construct Earth's orbit around the Sun
    - Represent the inner and outer limits of the habitable zone and determine whether Earth stays with the habitable zone throughout its orbit around the Sun

Routine

Think-Talk-Open Exchange is a structured discussion routine that allows students the opportunity to share with others and gain feedback on their ideas by finding similarities and differences, piecing together disparate bits of information, or reconciling different interpretations. Refer to the Earth & Space Science Course Guide for support with this routine.

Implementation Tip

This activity may feel a bit more teacher-led than other parts of this unit. Keep in mind that teaching students how to figure out orbital shape based on data is not an end in itself! Rather, this is another opportunity to interpret a mathematical model and use it as a tool to make evidence-based claims.

2. Point out to students that Earth does fall within the habitable zone throughout its orbit because the low eccentricity means it has a low distance between foci, and Earth's distance throughout orbit therefore does not change a lot.

3. Ask students to name which of the other exoplanets have a lower eccentricity than Earth's and therefore will also not change distance very much and stay within the habitable zone. Listen for students to say that trappist 1-f and trappist 1-g both have eccentricities lower than Earth. Let them know that for that reason they don't have to construct the orbit and can assume those planets stay within the habitable zone.

4. Have each student construct the orbit for Kepler 186 -f, Kepler 442-b, and TOI-2257.

5. After students have completed all three orbits, have groups of three use the group learning routine **Think-Talk-Open Exchange** to share what they figured out:
    - how they constructed the orbit for their assigned exoplanet;
    - how each variable in Kepler's First Law of Planetary Motion is represented in their model; and
    - their conclusions about whether the planet stays within the habitable zone throughout its orbit.

6. Use the table below for guidance on the answers to expect from students.

Elaborate: Which exoplanets orbit in the habitable zone?

Constructing an Orbit
Use Kepler's First Law of Planetary Motion to calculate the scaled distance between foci in the solar system of the exoplanet that was assigned to you. Then use the scaled distance between foci, scaled length of major axis, amd materials provided by your teacher to construct that exoplanets orbit in order to determine whether it stays within the habitable zone through an orbit around its host star.

Orbital Data

Celestial Object	Scaled Length of Major Axis (cm)	Eccentricity of Orbit	Scaled Distance Between Foci (cm)	Scaled Habitable Zone Range (cm)	Does the planet stay within the habitable zone?
Earth	15.209832	0.0329		14.21-25.07	
Kepler 79 b	36.056	0.0291		511.98-1265.30	
Kepler 442 b	61.19	0.04		48.62-85.72	
Kepler 432 b	15.01	0.6785		150.15-271.72	
Kepler 18 b	6.7	0.0000		218.86-482.75	
Kepler 186 f	6.7184	0.0769		3.62-6.94	
Trappist 1 b	5.74	0.1185		3.44-7.18	
HD 20782 b	15.10	0.6532		131.63-232.13	
HD 17156 b	11.89	0.5086		73.75-129.11	

Take Time for These Key Points

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

- We algebraically manipulated Kepler's First Law to isolate the unknown variable f, then plugged in our known values, e and d, in order to calculate f.
- The distance between the two centers of mass in the solar system, f, is represented by the two thumbtacks.
- The length of the orbit's major axis, d, is represented by the longest distance between two points on the orbit.
- The eccentricity of the orbit, e, is represented by how circular or elliptical the orbit is.
- Kepler 186 -f, Kepler 442 b, Trappist - 1f, and Trappist- 1g have a very circular orbit or low orbital eccentricity, so they stay within the habitable zone of their solar system throughout an entire orbit of their host star. TOI-2257 b's orbital shape is very oval like (eccentricity is very high), so while it does orbit within the habitable zone during part of its orbit, it does not stay within the habitable zone of its solar system throughout an entire orbit around its host star.

Which exoplanets stay within the habitable zone throughout their orbit around their stars?

Kepler 186 -f
Kepler 442 b
Trappist - 1f
Trappist 1 - g

All have a very circular orbit or low orbital eccentricity, so they stay within the habitable zone of their solar system throughout an entire orbit of their host star.

Orbital Data
Orbital eccentricity, length of major axis, and the distance between foci data for the exoplanets below comes from the NASA exoplanet archive. The length of string and distance between foci for student creation of orbits was calculated by multiplying all actual values for each planet by the same factor. Values to be used for student activity are in columns highlighted with blue.

Note: Habitable Zone should be measured from the focus that represents the star.

Celestial Object	**Major Axis** (million km)	**Scaled Length of Major Axis** (cm)	**Length of String** (cm)	**Eccentricity of Orbit**	**Distance Between Foci** (million km)	**Scaled Distance Between Foci** (cm)	**Habitable Zone Range** (million km)	**Scaled Habitable Zone Range** (cm)
Earth	299.2	60	30.5	0.0167	4.99664	1	142.12 - 172.04	28.5 - 34.5
Kepler 186 f	122.7	50	26	0.04	4.91	2	36.20 - 69.41	14.8 - 28.3
Kepler 442 b	137.330	50	26	0.04	4.63	2	37.70 - 79.44	16.3 - 34.4
TOI-2257	43.47	25	18.7	0.4960	21.56	12.4	11.82 - 24.98	6.8 - 14.4
Trappist 1 f	11.49	5.7	2.9	0.010	.114	.06	3.44 - 7.18	1.7 - 3.6
Trappist 1 g	14.03	7.0	3.5	0.002	.028	.01	3.44 - 7.18	1.7 - 3.6

Differentiation Point

Extension Activity
If students complete the Elaborate phase early and demonstrate mastery, remind them that one of the questions the class had about exoplanets they are investigating is whether they have an atmosphere. Provide data for planets in our solar system, including diameter, mass, and density data of different planets. Challenge them to look for patterns in our solar system data associated with the existence of an atmosphere on planets in our solar system. They should see a pattern in the relationship between mass and existence of an atmosphere and diameter and the existence of an atmosphere. Encourage them to think about why these relationships exist and use those patterns to make claims about the existence of an atmosphere on exoplanets in the performance task data set.

Evaluate

Developing or revising models to include new ideas about orbits

Students **develop new models or revise existing ones** to represent the idea that **stable** temperatures and the maintenance of liquid water result from **features of the motions of orbiting objects**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Small groups of 3-4 students (same groups from Unit Launch)	❑ Idea Carousel ❑ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Planets and Orbits Model Rubric ❑ Connect to the Performance Task: Planets and Orbits	None	❑ Driving Question Board ❑ Groups' revised models (charts) ❑ Class wide evidence-based claim poster ❑ *Connect to the Performance Task: Planets and Orbits Student Work*

Revise and Share Models

1. Ask students to consider their responses to these questions and what they have figured out about orbits, then represent their ideas about why the Sun has been able to support a planet where life has been able to exist and evolve on their initial group models from the performance task launch. These should go onto new pieces of chart paper
2. 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.

Routine

This routine allows for each group to give and receive warm feedback and suggestions around content and clarity in their model, as well as pose and respond to questions. The repeated use of **Idea Carousel** should support students in gaining familiarity with the routine and getting better at using it as a tool to surface thinking.

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 habitable zone range in our solar system is 142.12-172.04 million km and Earth orbits the Sun at an average distance of 150 million km, which is within the habitable zone.
- Earth's orbit is very circular, with an eccentricity of 0.0167, so it stays within the habitable zone throughout an orbit and maintains mostly liquid water. This is one of the major reasons earth can sustain life.

3. 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.
4. Allow groups to use peer feedback and ideas shared by other groups to go back and revise their model.

Access for Multilingual Learners

The routine **Idea Carousel** is ideal for **emerging language learners**. Students with only receptive language can simply engage by listening and adding annotations

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 Earth & Space Science Course Guide for support with this routine.

Return to the Performance Task

1. Using what they learned in the Idea Carousel, have students independently refine their models in their performance task research organizer. See the sample response below for an idea of the types of responses to expect at this stage in the unit.

2. After students complete their work, support them to use the rubric for this learning sequence as a self-reflection tool. Here are some ways the rubric can be used:
    a. Have students complete a self-assessment using the rubric.
    b. Create a piece of student work that is a fictional composite of a few different students' work, and complete a critique as a class, while students critique their own work using the rubric.
    c. Collect all the work and score the work, with an eye to how accurate students' self-assessments seem to be.

3. Assign students to partnerships and have them review one another's work and self-assessment and provide feedback on the accuracy of the self-assessment.

4. Give each student an opportunity to revise their model using what surfaced from their self-assessment and/or feedback.

5. Let students know that they will now use all the ideas represented in their models as a lens to analyze and interpret exoplanet data and finalize their performance task argument.

Access for All Learners

All students have learned and probably been curious about planets and the possibility of life on other planets. They've all certainly experienced and enjoyed water throughout their lives. The prompts at the end of the rubric are designed to support students in pausing to reflect about why their new ideas are relevant to their lives. After students complete the reflection prompts independently, consider facilitating a whole class share around why learning during this 5E is relevant to students' lives and displaying their responses somewhere in the classroom. This can help keep students motivated to continue the unit investigation.

Standards in Planets and 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
Developing and Using Models • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. SEP2(3) 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)	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)	Patterns • Mathematical representations are needed to identify some patterns. CCC1(4) 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 1	Explore/Explain 2	Elaborate	Evaluate
Developing and Using Models	Initial Model	Revising solar system Models	Developing a Mathematical Model of solar system Motion	Constructing an Orbit	Revised Performance Task Model
Using Mathematics and Computational Thinking			Verbal Explanation of Equation (Kepler's Third Law) Claims about exoplanets and habitable zone	Verbal Explanation of Equation (Kepler's First Law) Constructing an Orbit Think-Talk-Open Exchange	
ESS1.B Earth and the Solar System	Initial Model	See-Think-Wonder Summary Task	Verbal Explanation of Equation (Kepler's Laws)	Verbal Explanation of Equation (Kepler's Laws) Think-Talk-Open Exchange	Revised Performance Task Model
Patterns		See-Think-Wonder Class Consensus Discussion Summary Task	Summary Task		Revised Performance Task Model
Scale, Proportion, and Quantity			Class Consensus Discussion Summary Task	Think-Talk-Open Exchange	Revised Performance Task Model

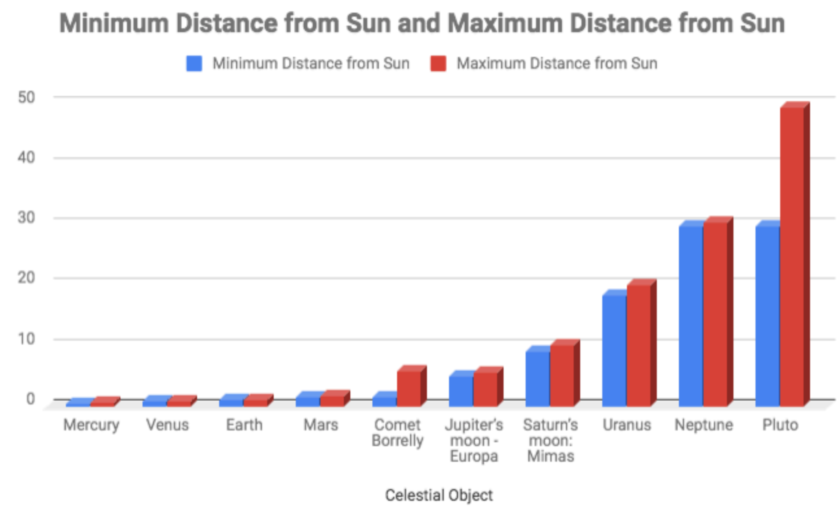
Common Core State Standards Connections

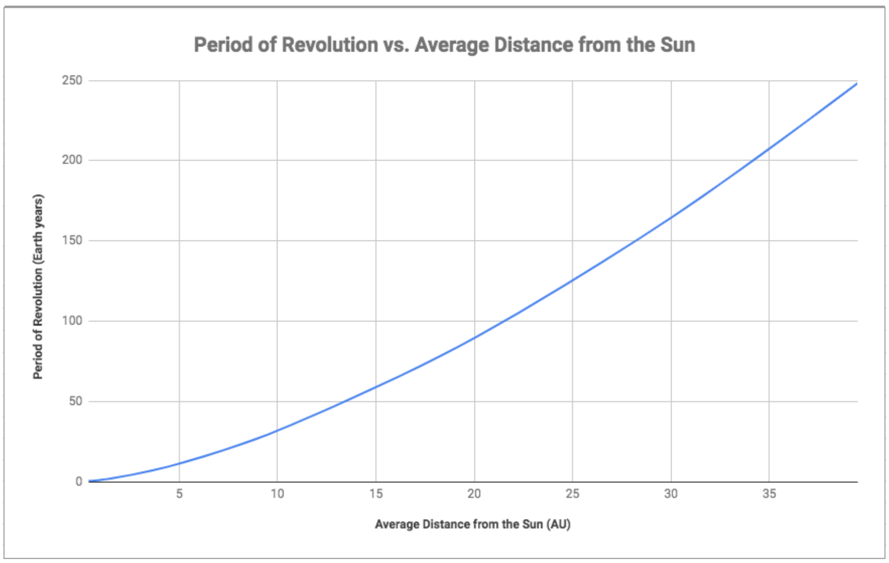
	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP2 MP4	MP2 MP4 HSA-SSE.A.1 HSA-CED.A.2	MP2 MP4 HSA-SSE.A.1 HSA-CED.A.4	MP2 MP4
ELA/Literacy		RST.9-10.1 RST.9-10.7 WHST.9-10.9 SL.9-10.4	RST.9-10.7 WHST.9-10.1 WHST.9-10.9 SL.9-10.5	RST.9-10.1 WHST.9-10.9	WHST.9-10.9 SL.9-10.5

Student Work for Planets and Orbits 5E

What are orbits like in our solar system? Student Work

Sample Graphs from Explore 1





See-Think-Wonder

See	Think	Wonder

• The planets and objects that have water in solid ice form are further from our Sun than Earth, where water is mostly liquid. • The planets and objects that have water in vapor/gas form are closer to our Sun than Earth. • The distance at which Comet Borrelly and Pluto revolve around the Sun changes a lot compared to other planets and objects in the solar system. • As the average distance at which an object orbits around the Sun increases so does the orbital period.	• I think this is because the further away you get from the Sun, the colder it is, so water is frozen. • I think this is because the closer you get to the Sun, the hotter it is, so water is a vapor form. • Earth is at just the right temperature for most of our water to exist in liquid form. • I think this might be the reason Comet Borrelly has water that is frozen most of the time, but every several years shoots out a jet of vaporized water and dust. • I think this is because if a celestial object orbits further away, its orbit is longer so it takes longer.	• Do the planets that have water in mostly ice and vapor form have any liquid water? Or did they ever? • Does comet Borrelly ever have water in liquid form? • Do the exoplanets we're investigating orbit around their stars at a distance that allows water to be in liquid form? Do they stay at that distance throughout an entire orbit around their star?

Connect to the Performance Task: Planets and Orbits Student Work

What makes Earth habitable?

After discussing how you would change your model with your group based on what you figured out about planets and orbits, record your revised model for what makes Earth habitable. Be sure to represent your understanding of the features of the motions of orbiting objects that lead to stability in temperature that can support the existence of life on Earth. Consider and respond to the following reflection prompt before you revise your model and cite evidence and reasoning for any changes you made:

Reflection Prompts

1. How was creating mathematical representations from data, like graphs and equations, useful in revising your model? Why might creating mathematical representations from data, like graphs and algebraic equations, be useful when developing a model for other phenomena?

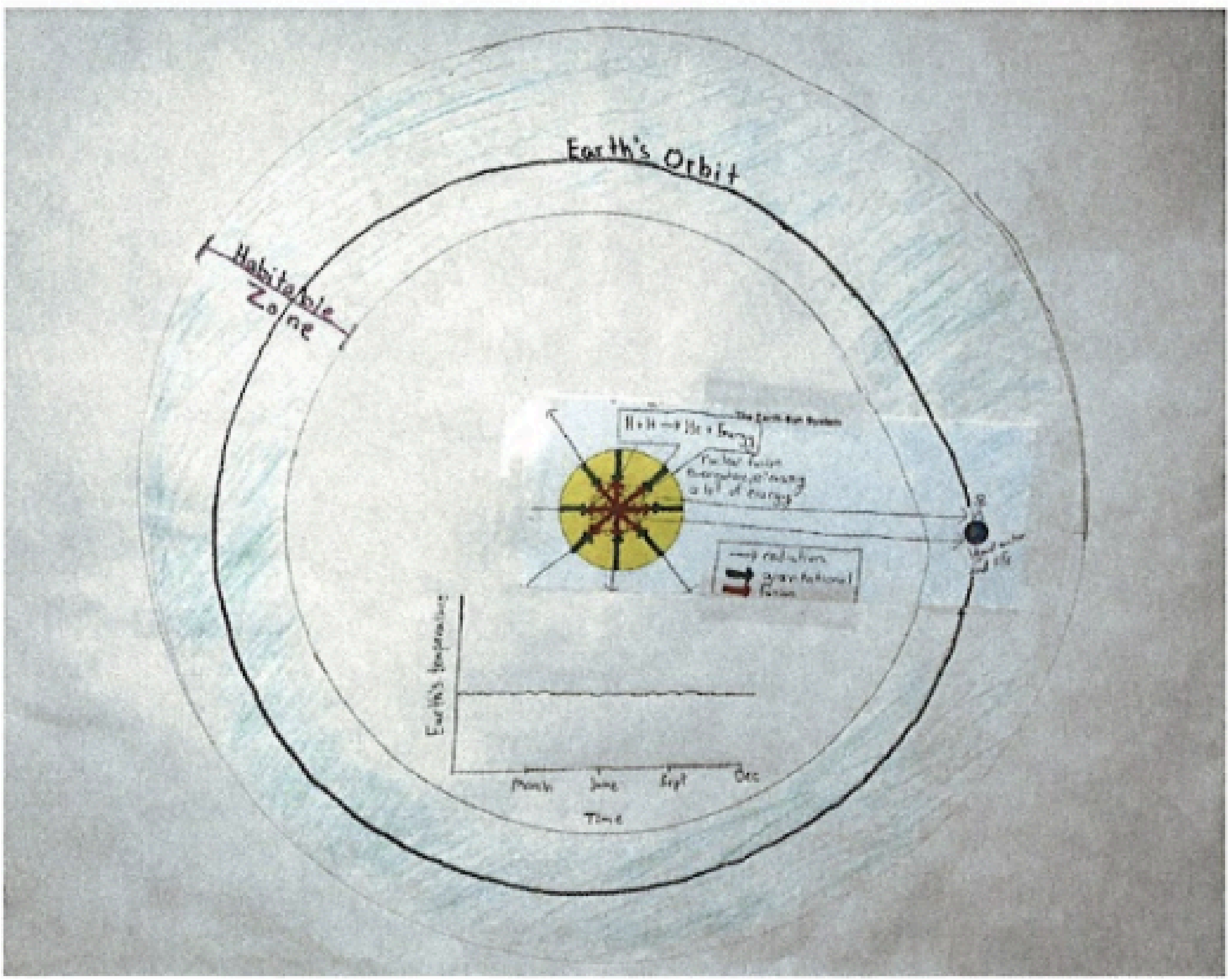
While the graph of orbital period vs semi major axis length allowed us to identify a pattern in the relationship between these two variables, the mathematical model described this pattern more accurately because it included exponents and a coefficient of star mass.

Revising Models Based on Evidence

1. Use the ideas captured in your responses to the reflection prompts to complete the table below and make changes to your model for why Earth is a planet that can sustain life.

Change to the Model	Evidence	Scientific Reasoning
we added an orbit that is within the right distance for liquid water to exist and that is relatively circular (low eccentricity). This is important for habitability and for life to be able to evolve.	Planets and objects in our solar system that orbit closer to the Sun than Earth only have traces of water in vapor form, while planets and objects beyond Mars only have water in ice form. objects like Comet Borrelly and Pluto have very elliptical orbits and experience dramatic climate swings.	Life as we know it needs liquid water to survive and somewhat stable temperature, so Earth having an orbit that is at the right distance and stays close to that distance throughout its revolution around the sun is a big reason Earth is able to sustain life.

2. In the space below, draw a revised version of your model for why Earth is a planet that can sustain life below.



Classroom Resources for Planets and Orbits 5E

Which Exoplanets Stay Within the Habitable Zone Example Class Response

Which Exoplanets Stay Within the Habitable Zone Example Class Response

which exoplanets stay within the habitable zone throughout their orbit around their stars?

Kepler 186 - f
Kepler 442 - b
TOI-2257 b
Trappist 1 - f
Trappist 1 - g

All are within the habitable zone of their solar system when they are orbiting at their average distance from their star.

we don't know for sure if they stay within the habitable zone throughout an entire orbit because we don't know the max and min distance at which they orbit (we don't know the orbit shape)

we need to know the shape of their orbits or the min and max distance

Unit Closing

Which exoplanet is most Earth-like?

Performance Expectations
HS-ESS1-1, HS-ESS1-3, HS-ESS1-4

Anchor Phenomenon
Out of all of the planets in the solar system, only Earth has life! Earth didn't have life for a long time, and now it does

Time
1-5 days

Based on the investigations and learning throughout the unit, students construct an argument based on evidence and reasoning about which exoplanet is the most Earth-like.

ANCHOR PHENOMENON	Which exoplanet is most Earth-like?	Students generate additional ideas about the habitability of exoplanets
DRIVING QUESTION BOARD	What questions 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	Which exoplanet is most likely to support life?	Based on their explanatory models for what has made Earth the only planet in our solar system that has been habitable, students argue from evidence about which exoplanet in the performance task data set is most likely to be habitable.
UNIT REFLECTION	How can we evaluate our learning in this unit?	Using a four corners strategy, students reflect on the use of technology in studying space science, the use of crosscutting concepts in figuring out the phenomena of the unit, and their learning about evidence-based claims. Students also reflect on whether traveling to an exoplanet is really a viable option for humans or not.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

Which exoplanet is most Earth-like?

Students generate additional ideas about the habitability of exoplanets

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Generating Ideas about Anchor Phenomenon

1. Students return to the anchor phenomenon and recall what is it about Earth that makes it the only planet in our solar system that has sustained life?

Driving Question Board

What questions 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

1. 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?

2. 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

Which exoplanet is most likely to support life?

Based on their explanatory models for what has made Earth the only planet in our solar system that has been habitable, students argue from evidence about which exoplanet in the performance task data set is most likely to be habitable.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Which exoplanet is most Earth-like? CER	None	

Returning to the Performance Task

1. Provide students with *Which exoplanet is most Earth-like? CER*. Prompt students to provide a written argument from evidence about which exoplanet in the performance task is most likely to be habitable. Remind students that it is important that they not only cite evidence from the exoplanet data set, but that they also connect that evidence to their claim by using ideas from their final models and other ideas from the unit.

Differentiation Point

The first page of *Which exoplanet is most Earth-like? CER* is a useful scaffold for some students as they organize their ideas prior to writing a formal argument. Students should have experience with writing arguments in middle school, but some may still need additional support with incorporating their ideas from the organizer into a formal argument. If students can write an argument without starting with the organizer, allow them to do so.

Encourage students who have already written a strong argument to think about which planets could have an atmosphere and what the thickness and pressure of a potential atmosphere might be. This is not something that was explicitly covered in the Planets and Orbits 5E, but students can consider each planet's proximity to its star and the planet's mass/gravity. Small terrestrial planets may have an atmosphere comparable to Earth's if they are not too close to their star, while larger jovian planets are likely to have an atmosphere that accounts for the majority of the planet's size and would have a pressure that would be too high for humans to survive.

Self Evaluation

1. Remind students that one of the main themes of this unit has been evidence-based claims and that their final argument is one type of evidence-based claim.
2. Prompt students to identify how their thinking has changed about what counts as an evidence-based claim. Support student ideas by projecting the initial and final class lists of what counts as an evidence-based claim.
3. Have students discuss ideas in their groups.
4. Provide students with the **Arguing from Evidence Rubric** to complete individually. Let them know that it's important they reflect thoughtfully because arguing from evidence is a practice they will engage in again in subsequent units, so they develop proficiency to argue from evidence at the high school level.

Unit Reflection

How can we evaluate our learning in this unit?

Using a four corners strategy, students reflect on the use of technology in studying space science, the use of crosscutting concepts in figuring out the phenomena of the unit, and their learning about evidence-based claims. Students also reflect on whether traveling to an exoplanet is really a viable option for humans or not.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Individual	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

1. Set up four posters around the room with the following prompts:
    a. What have you learned about the role of technology in studying space science?
    b. How has your thinking about what counts as evidence in a scientific argument changed since doing this unit?
    c. What are your thoughts about the feasibility of the class' proposed solution of humans settling on another planet? What are the pros and cons?
    d. How did thinking about patterns, scale, and stability & change help you make sense of the phenomena in this unit?

2. Have students reflect on their learning from the unit through a four corners discussion, where students gather at one of the four posters and discuss their thoughts about the prompt on the poster in pairs or triads.

3. Revisit the Driving Question Board to see if any lingering questions remain. If so, consider with students whether they will be addressed in future units, or whether it might inspire them to research the questions on their own or in other science courses.

Implementation Tip

If you have a large class, consider setting up two posters for each question, so that space and noise level is more conducive to student discussion.

Standards in Unit Closing

Performance Expectations

HS-ESS1-1 **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.**
Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.
Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.

In NYS, all occurances of the term "sun" in this PE have been formatted as "Sun."

HS-ESS1-3 **Communicate scientific ideas about the way stars, over their life cycle, produce elements.**
Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.
Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.

In NYS the clarification statement has been edited as follows: Emphasis is on the way nucleosynthesis varies as a function of the mass of a star and the stage of its lifetime.

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
		Systems and Systems Models • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. CCC4(3)

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Systems and Systems Models	*Final Task*	*Final Task*	*Final Task*	*Final Task*

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Mathematics				
ELA/Literacy				