Climate Change - Teacher Materials

Unit 4	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 4 Climate Change

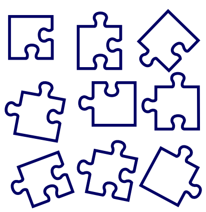
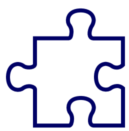
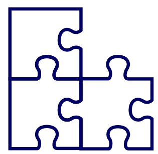
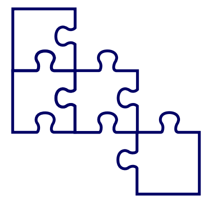
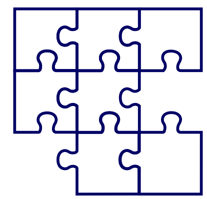
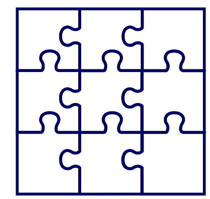
How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?

Performance Expectations
HS-ESS1-7, HS-ESS2-4, HS-ESS2-2, HS-ESS2-6, HS-ESS3-1, HS-ESS3-5

Time
23-29 days

Earth's temperature is rising, reversing the cooling trend that occurred over the past 2,000 years, putting millions of people in harm's way, yet the public is not convinced of the risks

Climate change is occurring today and it is already having vast implications for humans and the natural environment. While climate change has occurred in the past due to natural factors, there is a consensus among 99.9% of climate scientists that today's climate crisis is different because humans are the cause and therefore have the ability to take action that will mitigate changes and consequences. It is crucial that the public is empowered with knowledge and understanding of the problem in order to catalyze the policy and behavioral changes needed to avoid the worst of future climate scenarios.

Unit Opening	Seasons Optional 3E	Earth-Sun Dynamics 5E	Climate Feedbacks 5E	The Past and the Future 5E	Unit Closing
Anchor Phenomenon →		**5E Lessons connect learning to the performance task** →			**Performance Task**
					
How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	*How does the annual cycle of the Earth around the sun create seasonal temperature variations?*	*What factors have contributed to climate change in the past and are they contributing to climate change now?*	*What is causing global temperatures to rise, and why is the Arctic warming at almost 4 times the rate as the rest of the globe?*	*Have humans experienced dramatic climate change in the past? How have human populations been impacted by climate change, and how can that inform how we might be impacted by it in the future?*	*How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?*

Unit Introduction

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

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

This unit was intentionally designed to build on the third unit of this course, Earthquakes, Volcanoes, and Tsunamis: Who's at risk?, in which students construct scientific explanations. In Climate Change, students continue to engage with evidence to construct scientific explanations after using and analyzing data. The common embedded group learning routines and curriculum structures introduced in the first unit are revisited, providing students and teachers multiple opportunities to engage in a culture of collaborative sensemaking around a phenomenon. In this unit, students are encouraged to explain how international organizations can use the scientific understanding of the causes of tectonic hazards combined with the realities of differing vulnerability and population needs of different tectonically active regions.

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

Unit Coherence

In Unit 4, the overall question about the human causes of climate change and its impacts is intended to motivate student engagement across the unit. From the students' perspective, there should be a clear and explicit unit storyline that guides the sequence of activities. Rather than one long continuous unit, we have chosen to use an instructional model to develop four coherent sequences of lessons within Unit 4. Each sequence is based on students' questions and builds towards figuring out something that contributes to the overall unit-level question about how we know that humans are causing climate change and how that matters. This in turn allows students to construct a communication from data analysis explaining how scientists are sure that humans are causing climate change, predicted outcomes of climate change, and how populations will be impacted. The phenomena, the instructional model, and the routines embedded throughout the sequences of lessons are all used in service of coherence across Unit 4.

Phenomenon-Driven Instruction

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

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

Anchor Phenomenon

To support coherence, students are prompted to 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. If a teacher feels the anchor phenomenon will not be familiar or accessible to all students, we suggest relating it to similar, more familiar phenomena. It is important to notice that the phenomenon question anchoring the unit is different from the more generalized and abstracted science question for the unit. This difference is part of what helps make the unit more student-centered, rather than teacher-centered.

Investigative Phenomena

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

Storyline and Pacing Guide

Unit Opening	How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	**Performance Expectations**	**Anchor Phenomenon**	**Time** 0-2 days

Student Questions	What Students Do	Student Ideas
These questions motivate the unit storyline. • Why was Earth's temperature cooling before but is rising now? • Why are people being displaced by climate factors? • Why are scientists sure that humans are causing climate change? • Has the climate ever changed before, and if so, how did it impact populations? • How will climate change affect people now and in the future? • Why are scientists so sure that climate change is a big deal?	Students have discussions and watch videos about the impacts of climate change, the scientific consensus around humans being the cause of climate change, and the difference between public perception and reality. Students then make observations from several graphs that illustrate the reality of climate change and how it affects real people. Students are then introduced to the unit performance task which is focused on analyzing and interpreting data related to changes in climate in the past in order to better understand how we are so confident humans are the cause, so they can educate others in their community about the risks. Finally, students surface their initial ideas about what natural factors could have caused changes in climate in the past and generate questions that they want to investigate in order to make further sense of how and why climate has changed throughout human history.	*These ideas are revisited throughout the unit storyline.* • Over the past 2,000 years, Earth had been cooling, until about 200 years ago • Millions of people have been displaced because of weather-related incidents • The scientific consensus is that humans are causing climate change and that it is a big deal • The public is less certain that humans are causing climate change, don't know that scientists are certain it is humans, and don't all agree that it is a big deal

During the Driving Question Board routine, students ask questions about the survival of people and the relationship to climate change, and how we know that climate change is caused by people. Once that question surfaces, tell students that we will begin by investigating past causes of climate change in order to compare it to what is happening now.

Seasons Optional 3E	How does the annual cycle of the Earth around the sun create seasonal temperature variations?	**Performance Expectations** HS-ESS1-7	**Investigative Phenomenon** The Earth experiences seasonal temperature variations, and different parts of the planet experience different seasons at different times.	**Time** 3 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • How does the sun contribute to climate? • How is climate change different from seasonal temperature variation?	Connecting to students' ideas that climate is related to sunlight, students use physical and computational models to determine how much sunlight reaches Earth at different times of year. Students analyze how the tilt of the Earth contributes to the amount of radiation reaching different latitudes of Earth and how that relates to seasonal differences.	*Students figure out these ideas in this 5E sequence.* • Seasonal variation in temperatures is due to Earth's tilt and its relative position compared to the sun as it orbits the Earth

After explaining how the amount of sunlight reaching different latitudes of Earth causes seasonal temperature variations, students have the requisite knowledge needed to proceed to understanding how Earth's orbit has changed over time, causing climate changes over long timescales compared to annual timescales.

Earth-Sun Dynamics 5E	What factors have contributed to climate change in the past and are they contributing to climate change now?	**Performance Expectations** HS-ESS2-4	**Investigative Phenomenon** The amount of radiation received at 65°N has gone up and down over the last 750,000 years and repeats a pattern about every 100,000 years.	**Time** 5 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. • How does the sun contribute to climate change? • What was the planet's orbit like in the past and what is it like now? • Has the Earth always had the same tilt, or does it change? • Can these factors explain climate change in the past? • What's their impact on the current climate?	Connecting to their earlier questions about how Earth's temperature has varied in the past, students observe patterns in global average temperature over the last 400,000 years and generate initial ideas and questions related to whether Earth's position with respect to the Sun is the cause of these patterns. Students then use models of Earth's eccentricity, tilt, and direction of tilt cycles to collect empirical evidence and develop a model to provide a mechanistic account for how Earth's position with respect to the Sun contributes to glacial-interglacial cycles. Additionally, students analyze sun radiation output data in order to determine whether the Sun's radiation output impacted climate change events in the past. Finally, students revisit the performance task to evaluate claims about how fluctuating temperatures influenced human evolution, and develop a model to provide a mechanistic account for how Earth's position with respect to the Sun and the Sun's output are impacting radiation reaching Earth today.	*Students figure out these ideas in this 5E sequence.* • Temperatures on Earth have fluctuated greatly during human history, marked by glacial and interglacial periods. • There seems to be a pattern in the frequency with which these fluctuations occur. • This pattern can be explained by cyclical changes in the shape of Earth's orbit and its tilt with respect to the Sun. • These changes cause ice sheets to recede and expand. • The orbit and tilt of the Earth today suggests Earth should be in a cooling period, so global temperatures are increasing today despite this.

After explaining how glacial-interglacial cycles were caused by changes in Earth's orbital cycles, students are able to determine that the current phase of Earth's orbital cycles suggests the Earth should be in a cooling phase which explains the cooling trend over the last 2000 years until the Industrial Revolution, which they observed in the unit launch.

Climate Feedbacks 5E	What is causing global temperatures to rise, and why is the Arctic warming at almost 4 times the rate as the rest of the globe?	**Performance Expectations** HS-ESS2-2, HS-ESS2-4, HS-ESS2-6	**Investigative Phenomenon** The globe is warming, and the average temperature of the Arctic is increasing at almost 4 times the rate as the rest of the globe.	**Time** 7-9 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. **From the Unit Launch** • What do greenhouse gases have to do with climate change? • How are humans causing climate change? • What is the relationship between ice sheets and warming? **From the Earth-Sun Dynamics 5E** • If the sun isn't causing warming, then what is?	First, students investigate the greenhouse effect to explain the relationship between human activity and climate change. Then, students observe changes in ice sheets to determine why the Arctic is warming at 4x the rate of the rest of the planet. Finally, students combine feedback mechanisms from the albedo affect and greenhouse gases in order to predict how warming temperatures could impact other climate factors as the world continues to heat.	*Students figure out these ideas in this 5E sequence.* • The greenhouse effect explains why increasing amounts of carbon dioxide leads to global warming • Albedo is the tendency of a surface to reflect or absorb radiation. • Ice has a high albedo compared to seawater and land. • As more ice forms because of less heating of Earth's surface, more radiation is reflected and more ice is formed. • Because seawater is dark green, it reflects much less radiation from the Sun and instead of absorbs it, meaning more radiation is heating Earth's surface. • As less ice forms because of more heating of Earth's surface, less radiation is reflected / more absorbed and more ice melts. • Ice melting creates a feedback loop that amplifies climate change • Warming also amplifies greenhouse gas levels, leading to another positive feedback loop • We are confident that human activities have set off this chain of events

After explaining the mechanism connecting burning fossil fuels to climate change and arctic amplification, students are left with the question of why scientists are convinced that this change is a big deal. This remaining piece is investigated in the last 5E.

The Past and the Future 5E

Have humans experienced dramatic climate change in the past? How have human populations been impacted by climate change, and how can that inform how we might be impacted by it in the future?

Performance Expectations
HS-ESS2-4, HS-ESS3-1, HS-ESS3-5

Investigative Phenomenon
When climate change has occurred in the past, human populations have been impacted. The current climate change event is predicted to affect populations in the future as well.

Time
7 days

Student Questions	What Students Do	Student Ideas
These questions motivate this 5E sequence and the unit storyline. **From the Unit Launch** • How has climate change affected people in the past? • Why is climate change a big deal? **From the Climate Feedbacks 5E** • What happened in the warming event after the last glacial maximum?	Students consider the rapid climate change events that occurred coming out of the last glacial maximum, which resulted in a dramatic slow down of the AMOC and plunged the northern hemisphere into an ice age. Students analyze how those rapid changes affected populations, and use that information to consider how climate change might impact people now. Students continue to analyze data about ice melt today and read about how sea ice melt is already affecting people in order to explain why climate change is a big deal.	*Students figure out these ideas in this 5E sequence.* • AMOC is slowing as the ice sheets have been melting. • When we decreased the amount of salt at the poles in our ocean current models, the current formed but it took longer to form and it moved more slowly when compared to the control. • When we increased the amount of salt at the poles, the current formed more quickly and it moved faster when compared to the control. • Ocean currents could have slowed or sped up in the past when ice sheets were retreating and expanding. • The Younger Dryas sudden cooling event can be explained by a slow down of AMOC, which in turn caused a mini ice age in the northern hemisphere that had major implications for human populations. • AMOC was overturned by melting northern ice sheets, causing an accumulation of warm water at the equator where the Sun's radiation is most concentrated. • The difference in temperature between ocean water at the equator and ocean water at the south pole increased, causing the amount and rate of warm water flow toward the south pole to increase. • Since the amount and rate of warm water flowing toward the south pole increased, more carbon dioxide was transferred to the atmosphere from the southern oceans and from permafrost and terrestrial biota to the atmosphere, leading to further temperature increases in the southern hemisphere. • Ice sheets are melting at an alarming rate • People globally are already being impacted by climate change

After explaining how scientists are certain that humans are causing climate change, students still need to address why it is a problem and how it could impact people. To understand that, students analyze how climate change has impacted populations in the past, how the current scenario is similar to past events, and how it is already impacting populations.

Unit Closing

How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?

Performance Expectations
HS-ESS3-1, HS-ESS3-5

Anchor Phenomenon

Time
1-3 days

Student Questions	What Students Do	Student Ideas
• How can we communicate clearly about climate change?	Students use their learning from this unit to construct a communication to someone in their community in which they explain why scientists are certain that humans are causing climate change, predict how climate factors will be affected, and explain how it will impact populations.	• Climate change is definitely caused by human activity • Increasing temperatures will affect a wide range of climate variables, including sea ice extent, ocean temperatures, food supplies, flooding, and precipitation • Climate change will affect large populations through weather related disasters and food shortages

At the end of this unit, students are able to produce communication in which they are able to combine their data analysis from the unit to disprove a skeptic claiming that climate change is not human caused or not a big deal

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-ESS1-7 Clarification Statement:
Assessment Boundary:

This PE, added by NYS, is not in the NGSS: Construct an explanation using evidence to support the claim that the phases of the moon, eclipses, tides and seasons change cyclically. [Clarification Statement: Emphasis of the explanation should include how the relative positions of the moon in its orbit, Earth, and the Sun cause different phases, types of eclipses or strength of tides. Examples of evidence could include various representations of relative positions of the Sun, Earth and moon.] [Assessment Boundary: Assessment does not include mathematical computations to support explanations but rather relies on conceptual modeling using diagrams to show how celestial bodies interact to create these cyclical changes.]

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

In NYS the clarification statement has been edited as follows: Examples of the causes of climate change could include those that differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation, solar output; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition and plate tectonic.

HS-ESS2-2 **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.**
Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.
Assessment Boundary: None

In NYS the clarification statement has been edited as follows: Examples of data could include descriptions of climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples of data could also include descriptions other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.

HS-ESS2-6 **Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.**
Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.
Assessment Boundary: None

HS-ESS3-1	**Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.** Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised. Assessment Boundary: None

In NYS, the clarification statement has been edited as follows: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards could include those from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as blizzards, hurricanes, tornados, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations could include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.

HS-ESS3-5	**Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition). Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.

In NYS the clarification statement has been edited as follows: Examples of evidence could include both data and climate model outputs that are used to describe climate changes...

Three-Dimensional Learning Goals in This Unit

Given the breadth of three-dimensional standards for high school Earth and Space Science, Unit 4 focuses primarily on ideas related to Earth's climate. These ideas fall within Core Ideas ESS2 and ESS3 of the NGSS/NYSSLS, *Earth's Systems* and *Earth and Human Activity*. This unit also engages students' use of the SEP of Thinking Mathematically and has a secondary focus on the SEP of Constructing Explanations and Designing Solutions. 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 patterns in Earth's processes and systems allows scientists to determine the structure and composition of Earth. Two secondary CCCs for the unit, Energy and Matter and Stability and Change are also useful to students as they use these ideas in two ways: (1) examining the changes to Earth's surface as a result of tectonic activity and; (2) developing explanations for how energy and matter move together during tectonic activity. 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 4

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
Developing and Using Models	ESS1.B Earth and the Solar System	Patterns
Analyzing and Interpreting Data	ESS2.A Earth Materials and Systems	Cause and Effect
Constructing Explanations and Designing Solutions	ESS2.D Weather and Climate	Energy and Matter
	ESS2.E Biogeology	Stability and Change
	ESS3.A Natural Resources	
	ESS3.B Natural Hazards	
	ESS3.D Global Climate 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
ESS3.D Global Climate Change
This unit builds on the following aspects of Global Climate Change in middle school:

- In middle school, students were exposed to the fact that human activities are major factors in the current rise in Earth's mean surface temperature, and that reversing this trend will take a combination of science, engineering, technology, and human behavior. In this unit, students build on that foundational knowledge to quantify and model the magnitudes and impacts of these changes.

Crosscutting Concepts from Middle School
Cause and Effect
This unit builds on the following aspects of Cause and Effect in middle school:

- Students in middle school have experienced determining relationships as causal or correlational. In this unit, students build upon that practice by using empirical evidence and causal mechanisms to differentiate between cause and correlation and to make claims about specific causes and effects.

Science and Engineering Practices from Middle School
Analyzing and Interpreting Data
This unit builds on the following aspects of Analyzing and Interpreting Data in middle school:

- Students in middle school have experience analyzing and interpreting data using graphs to identify relationships and identify evidence for phenomena. This unit builds on that background by asking students to use tools, technology, and models to make valid and reliable scientific claims based on data.

Assessment

Performance expectations (PEs) in the NGSS describe what students should know and be able to do. Unit 4 targets a bundle of five PEs taken from the second and third core ideas in high school Earth and Space Science (ESS2, ESS3); those standards are HS-ESS2-2, HS-ESS2-4, HS-ESS2-6, HS-ESS3-1, and HS-ESS3-5. This PE bundle informs the types of three-dimensional tasks in which students engage across the unit. Each sequence of lessons within the unit targets elements from one or more of the performance expectations for the unit, and the teacher has opportunities to collect evidence of student learning around these elements within that learning sequence. The unit-level Performance Task only targets a subset of three-dimensional learning goals informed by the bundled PEs for the unit. All other evidence of learning related to the other dimensions/elements in the PEs can be found within the instructional sequences. The **Teacher Materials** for each sequence of lessons includes a matrix that lists which student artifacts can provide evidence of student learning for each of three-dimensional learning goals from that sequence.

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

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

	Seasons Optional 3E	Earth-Sun Dynamics 5E	Climate Feedbacks 5E	The Past and the Future 5E
Developing and Using Models		✔	✔	✔
Analyzing and Interpreting Data		✔	✔	✔
Constructing Explanations and Designing Solutions	✔			
ESS1.B Earth and the Solar System	✔	✔		
ESS2.A Earth Materials and Systems		✔	✔	✔
ESS2.D Weather and Climate		✔	✔	✔
ESS2.E Biogeology		✔		
ESS3.A Natural Resources				✔
ESS3.D Global Climate Change				✔
Patterns	✔			
Cause and Effect		✔	✔	✔
Energy and Matter		✔	✔	✔
Stability and Change			✔	✔

At the end of Unit 4, 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 4 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.
MP3 Construct viable arguments and critique the reasoning of others.	Mathematically proficient students understand and use stated assumptions, definitions, and previously established results in constructing arguments. They make conjectures and build a logical progression of statements to explore the truth of their conjectures. They are able to analyze situations by breaking them into cases, and can recognize and use counterexamples. They justify their conclusions, communicate them to others, and respond to the arguments of others. They reason inductively about data, making plausible arguments that take into account the context from which the data arose. Mathematically proficient students are also able to compare the effectiveness of two plausible arguments, distinguish correct logic or reasoning from that which is flawed, and—if there is a flaw in an argument—explain what it is. Elementary students can construct arguments using concrete referents such as objects, drawings, diagrams, and actions. Such arguments can make sense and be correct, even though they are not generalized or made formal until later grades. Later, students learn to determine domains to which an argument applies. Students at all grades can listen or read the arguments of others, decide whether they make sense, and ask useful questions to clarify or improve the arguments.
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.
MP6 Attend to precision.	Mathematically proficient students try to communicate precisely to others. They try to use clear definitions in discussion with others and in their own reasoning. They state the meaning of the symbols they choose, including using the equal sign consistently and appropriately. They are careful about specifying units of measure, and labeling axes to clarify the correspondence with quantities in a problem. They calculate accurately and efficiently, express numerical answers with a degree of precision appropriate for the problem context. In the elementary grades, students give carefully formulated explanations to each other. By the time they reach high school they have learned to examine claims and make explicit use of definitions.

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.

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.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.

Implementing Unit 4

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

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

The first time enacting any unit with students may take longer than anticipated, particularly if the pedagogical approach is significantly different from what a teacher is used to. A teacher may want to skip entire lessons or activities, or revert to more traditional approaches when it seems like time is running out. We often ask teachers to think about the best way to modify recipes. Just like when using a recipe for the first time, it’s a good idea to stay as true to the materials as possible before making modifications or substitutions! As teachers become more familiar and comfortable with the instructional model, the embedded routines, and three-dimensional teaching overall, the desire to skip things will dissipate. Teachers using our curriculum over time have noticed that they are able to move a bit quicker through this and other NGSS-designed units each 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	Seasons Optional 3E	Earth-Sun Dynamics 5E	Climate Feedbacks 5E	The Past and the Future 5E	Unit Closing
Class Consensus Discussion		1	1	2	3	
Domino Discover	1	2	3	3	3	
Driving Question Board	1					
Idea Carousel		1				
Read Generate Sort Solve					1	
Rumors	1			1		
Tell the Story	1					
Think-Talk-Open Exchange				2	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	Seasons Optional 3E	Earth-Sun Dynamics 5E	Climate Feedbacks 5E	The Past and the Future 5E	Unit Closing
Cause-and-Effect Chart				1		
Sequence Chart					1	
Text Annotation	1			1		

Simulations in this Unit

Lesson	Simulation Title	Source	Technical Notes	Permissions Notes
Seasons Optional 3E	Seasons and Ecliptic	http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html	NA	NA
Earth-Sun Dynamics 5E	The direction of Earth's tilt with respect to the Sun	https://drive.google.com/file/d/1C8M2kkTURmyNpICf_3si6a_usGLIFmHU/view	NA	NA
Earth-Sun Dynamics 5E	The Vostok Core and Milankovitch Cycles	http://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html	NA	NA
Climate Feedbacks 5E	Greenhouse Effect	https://phet.colorado.edu/sims/html/greenhouse-effect/latest/greenhouse-effect_all.html	NA	NA

Lesson	Simulation Title	Source	Technical Notes	Permissions Notes
The Past and the Future 5E	IPCC WGI Interactive Atlas: Regional information (Advanced)	https://interactive-atlas.ipcc.ch/regional-information#eyJ0eXBlIjoiQVRMQVMiLCJjb21tb25zIjp7Imxhd CI6OTc3MiwibG5nIjo0MDA2OTIsInpvb20iOjQsInByb2oiOiJFUFNHOjU0MDMwIiwibW9kZSI6ImNvbXBsZXRlX2F0bGFzIn0sInByaW1hcnkiOnsic2NlbmFyaW8iOiJzc3A1ODUiLCJwZXJpb2QiOiJuZWFyIiwic2Vhc29uIjoieWVhciIsImRhdGFzZXQiOiJDTUlQNiIsInZhcmlhYmxlIjoic2xyIiwidmFsdWVUeXBlIjoiQU5PTUFMWSIsImhhdGNoaW5nIjoiU0lNUExFIiwicmVnaW9uU2V0IjoiYXI2IiwiYmFzZWxpbmUiOiJBUjYiLCJyZWdpb25zU2VsZWN0ZWQiOltdfSwic2Vjb25kYXJ5Ijp7ImFjdGl2ZSI6ZmFsc2UsIm1hc2siOiJub25lIiwic2NhdHRlcnBsb3QiOiJub25lIn19	NA	NA

Videos in this Unit

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Unit Opening	How do you feel climate change?	https://www.youtube.com/watch?v=iS0dJ0divP8	NA	NA
Unit Opening	Climate Change Devastates Refugee Communities	https://www.youtube.com/watch?v=9-oiZNzKl_s	NA	NA
Seasons Optional 3E	Insolation Part 2a- Reasons for the Seasons	https://www.youtube.com/watch?v=-O9XR0AAxXY	NA	NA

Lesson	Video Title	Source	Technical Notes	Permissions Notes
Earth-Sun Dynamics 5E	Northern Hemisphere Ice Coverage Over 400,000 years	https://www.youtube.com/watch?v=8lt3uhToMCI	NA	NA
Earth-Sun Dynamics 5E	The Rise and Fall of Ice Age Glaciers	https://sealevel.nasa.gov/resources/100/video-watch-glaciers-rise-fall-in-thousands-of-years-per-second/	NA	NA
Climate Feedbacks 5E	As Arctic warms, Indigenous communities there face dramatic changes to their way of life	https://www.youtube.com/watch?v=Yp-eNd0VGzg	NA	NA
Climate Feedbacks 5E	Evidence Links Human Activity to Global Warming | Decoding the Weather Machine	https://ny.pbslearningmedia.org/resource/nvdtwm-sci-humanevidence/evidence-links-human-activity-to-global-warming-decoding-the-weather-machine/	NA	NA
Climate Feedbacks 5E	How hot is asphalt or cement in summertime?	https://www.youtube.com/watch?v=PD5LWwya2Pc	NA	NA
Climate Feedbacks 5E	The Rise and Fall of Ice Age Glaciers	https://www.youtube.com/watch?v=P4gs4tg_vQQ	NA	NA
Climate Feedbacks 5E	Earth's Albedo and Global Warming | PBS LearningMedia	https://ny.pbslearningmedia.org/resource/ipy07.sci.ess.watcyc.albedo/earths-albedo-and-global-warming/	NA	NA
The Past and the Future 5E	The Blue Marble	https://www.youtube.com/watch?v=C3Jwnp-Z3yE	NA	NA

Lesson	Video Title	Source	Technical Notes	Permissions Notes
The Past and the Future 5E	AMOC Model	https://www.youtube.com/watch?v=eZzpvLz4yAk	NA	NA
The Past and the Future 5E	The Catastrophic Flood that Triggered an Ice Age	https://www.youtube.com/watch?v=qMVhR26NRsk	NA	NA
The Past and the Future 5E	What The US Would Look Like If All The Earth's Ice Melted	https://www.youtube.com/watch?v=dW5e61XSMHk	NA	NA
The Past and the Future 5E	These crops are suffering most from climate change | World Economic Forum	https://www.weforum.org/videos/these-crops-are-suffering-most-from-climate-change/	NA	NA
The Past and the Future 5E	How Climate Extremes are Causing World Hunger	https://www.youtube.com/watch?v=3nEelCjeldU	NA	NA

Lab Materials in this Unit

Lesson	Lab	Materials needed (per group)
Seasons Optional 3E	What Causes Seasons Investigation Lab minutes: 90 minutes	❏ Heat lamp ❏ Inflatable globe ❏ 3 thermometers ❏ Tape ❏ Large square grid paper ❏ Markers ❏ Stopwatch
Earth-Sun Dynamics 5E	Orbital Factors Investigation Lab minutes: 90 minutes	❏ Small flashlight ❏ Sphere or globe 6 inches in diameter ❏ markers / pen / pencil
Climate Feedbacks 5E	Carbon Dioxide and Air Temperature Investigation Lab minutes: 45 minutes	❏ Calculator

Lesson	Lab	Materials needed (per group)
Climate Feedbacks 5E	Ice and Radiation Investigation Lab minutes: 45 minutes	❏ 4 cups or jars ❏ Green blue black and white construction paper ❏ 4 thermometers ❏ Tape ❏ Scissors ❏ Timer ❏ Heat lamp
The Past and the Future 5E	Melting Ice Investigation Lab minutes: 90 minutes	❏ Two large clear containers or tanks of water ❏ Blue and red food coloring with one additional color recommended ❏ Cold very salty water (recommended concentration of 400g/L NaCl) ❏ Cold freshwater ❏ Warm water

Other Materials in this Unit

Lesson	Materials needed
Unit Opening	❏ Chart Paper ❏ Sticky Notes ❏ Chart paper ❏ Sticky notes
Seasons Optional 3E	❏ Poster paper ❏ Markers and colored pencils ❏ Class Consensus Discussion Steps ❏ The Seasons
Earth-Sun Dynamics 5E	❏ Map of Greenland ❏ Poster paper ❏ Markers and colored pencils ❏ Class Consensus Discussion Steps ❏ *Sample Class Energy Budget Model After Earth-Sun Dynamics*

Lesson	Materials needed
Climate Feedbacks 5E	❑ Driving Question Board ❑ Ideas for Investigations Chart ❑ Class Consensus Discussion Steps ❑ Chart paper ❑ From the first 5E: Global Consensus Model: Global Energy Budget ❑ Sea Ice Extent Since 1980 ❑ Documenting Glacial Change | PBS LearningMedia ❑ How to make a line graph in Google Sheets ❑ Class Consensus Discussion Steps ❑ Chart paper ❑ From the last investigation: Class Consensus Model: Global Energy Budget ❑ Card sort made from *Ice Caps Cause and Effect Cards* ❑ *Greenhouse Gas Feedback Mechanisms* ❑ Chart paper ❑ Chart Paper ❑ Sticky Notes
The Past and the Future 5E	❑ Driving Question Board ❑ *The End of the Clovis Population Cards* ❑ From the previous 5E: Class Consensus Model: Global Energy Budget ❑ Sea Level Change Data Spreadsheet ❑ Chart Paper ❑ Class Consensus Discussion Steps ❑ Chart paper ❑ Sticky Notes
Unit Closing	❑ Driving Question Board

Teacher Materials for Unit 4

Unit Opening

How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	**Performance Expectations**	**Anchor Phenomenon**	**Time** 0-2 days

Climate change is occurring today and it is already having vast implications for humans and the natural environment. While climate change has occurred in the past due to natural factors, there is a consensus among 99.9% of climate scientists that today's climate crisis is different because humans are the cause and therefore have the ability to take action that will mitigate changes and consequences. It is crucial that the public is empowered with knowledge and understanding of the problem in order to catalyze the policy and behavioral changes needed to avoid the worst of future climate scenarios.

ANCHOR PHENOMENON		
PERFORMANCE TASK	Students review the Performance Task.	Review the Performance Task with students.
DRIVING QUESTION BOARD	What questions do we have? What data do we need to figure out the answers to these questions?	Based on ideas that have surfaced through student discussion, students create a driving question board and develop ideas for investigations that will drive the unit.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Domino Discover ❏ Tell the Story	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ Tell the Story ❏ Performance Task Introduction ❏ Initial Model	None	❏ Chart Paper ❏ Sticky Notes ❏ How do you feel climate change? ❏ Climate Change Devastates Refugee Communities

Unit Launch

1. Remind students that we started to talk about climate change in unit 1, and acknowledge that they've likely heard a lot about it in the media. Tell students that the class will have an opportunity to discuss what they already know about climate change.

2. Have students share what they know about the effects climate change has on humans and the natural environment and what is causing climate change to occur by asking them to discuss the prompts below in their table groups.
    i. What effects does climate change have on humans and the natural environment?
    ii. What is your current understanding of what is causing climate change?

Note: If it is helpful, refer students back to the Unit 1 launch (tell the story texts in the PTO) where they observed changes to the planet.

3. Ask groups to decide on one idea to share in response to each of the two prompts above. Use the **Domino Discover** group learning routine, to surface student ideas in response to the two prompts above. Document these ideas for the class on chart paper or the board.

Look & Listen For

Possible student ideas:

- Some species have gone extinct because of climate change in the past and today.
- Today, many species are dying at a fast rate because of environmental changes due to climate change
- Migratory patterns of fish humans eat are changing, impacting food sources for populations.
- Low lying island nations and cities are going under water as sea levels rise.
- It's influencing/affecting droughts, wildfires, and extreme temperatures and storms today, making life hard for some people around the world.
- Burning of fossil fuels produces greenhouse gases
- Other greenhouse gases humans are generating
- Natural factors could also be contributing
- The sun is getting hotter/stronger
- The hole in the ozone layer is causing climate change

4. Acknowledge the fact that students have surfaced several significant problems climate change has caused. Tell them that scientists are also concerned about these challenges and other negative outcomes, but that there is a disconnect between public and scientists' perceptions of climate change.

5. Ask students: how do you think lingering skepticism can impact our abilities to respond to climate change?

6. Let students know that part of the reason scientists are so sure humans are causing global temperatures to rise is that a large part of their research involves analyzing and interpreting data about natural changes in climate throughout Earth's history. Let them know that they are going to have a chance to watch a video and start looking at some of the data scientists have analyzed, then generate questions, in order to better understand what scientists are seeing in the data.

Tell the Story

1. Show the videos How do you feel climate change? and Climate Change Devastates Refugee Communities . Tell students that they will now have a chance to better understand the current status of climate change and its impacts and public perceptions by looking at three texts and identifying important details about this story.

2. Provide students with the *Tell the Story* handout.

3. Have students read and annotate the three texts, circling or highlighting three details that are the most important to the phenomenon being described.

4. Students share their ideas in their group, with every individual identifying the details that they thought were important.

Conferring Prompts

Confer with students as they tell the story.

- Why do you think this detail is important?
- Did your group members and you circle or highlight the same details?
- How did you agree, as a group, about the most important details?

5. Use the **Domino Discover** group learning routine, to surface student ideas. Document these ideas for the class.

Look & Listen For

- Global temperatures were declining for nearly 2,000 years
- Global temperatures have been dramatically increasing since around 1850
- Climate and weather-related events displaced millions of people in 2023, largely from floods and storms
- A large majority of scientists believe that humans are causing climate change and that it is a problem, but the public perception is that there is ambiguity in the reality and cause of climate change

Performance Task

Students review the Performance Task.

Review the Performance Task with students.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Performance Task Introduction ❏ Initial Model	None	

Reviewing the Performance Task

1. Ask students what ideas they have about why so many US citizens don't believe humans are the cause of climate change, and about one third are not concerned about the impact on humans and the natural environment, despite the consensus among scientists and their concerns about the implications. Have students turn and talk to each other for about one minute and ask several students to share out.

Look & Listen For

Possible student ideas:

- Social media
- Misinformation from climate deniers
- Politicians
- Some people they think it because of natural factors
- Most people don't understand what scientists understand

2. Provide students with the handout Introduction to the Unit Performance Task and review the task "Educating your Community about the Predicted Impacts of Climate Change on Human Populations."

Surfacing Student Ideas

1. Ask students to consider what you have learned in previous investigations in the course and their prior knowledge about what causes a planet's or other solar system object's temperature to change over time and list ideas in response to the following prompt: *What factors impact temperature and change in temperature on Earth and other planets and objects?*.

2. Using the directions in the handout "Developing an Initial Model," have students work in table groups to develop a model (diagram) on poster paper that illustrates the factors they think can cause Earth's temperature to change.

3. Tell students to identify the idea they feel most confident about, and write it on a post-it note.

4. Using the **Rumors** routine, students share out ideas with the class.

5. Classify student ideas on the board to surface patterns.

Look & Listen For

Possible student ideas:

- The amount of sunlight reaching a planet or object
- Earth's orbit / position of the Earth with respect to the Sun
- Water - oceans, large bodies of water, and ice
- Geography in general - land and landforms
- Location on Earth
- Volcanic eruptions
- Asteroids
- Burning fossil fuels - increase in carbon dioxide and other greenhouse gasses and pollution in the atmosphere

6. Let students know that it's ok if there is some disagreement across groups, as they will have an opportunity to investigate climate factors and confirm, refine, or change their initial ideas.

Routine

Rumors routine is used to surface student ideas and look for patterns in student answers. Use the look and listen for, to guide students during the discussion.

Driving Question Board

What questions do we have? What data do we need to figure out the answers to these questions?

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

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Driving Question Board	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	❑ Chart paper ❑ Sticky notes

Generating Questions

1. At this point, students should have a lot of questions! Let them know that they will be investigating why and how climate change has occurred in the past, how it impacted human populations, and what our learning tells us about climate change and its implications for us today.

2. Remind students that our goal of this unit is to disprove skeptics who claim that climate change is not caused by humans. Prompt students to consider what they need to investigate in order to rule out

3. Have students independently come up with questions they think need to be answered in order to figure out why climate change has occurred in the past, how it impacted human populations, and how it compares to today.

4. Have students write each one of their questions on a separate post-it note.

5. As a whole class or in small groups, have students share and categorize their questions on chart paper. Ideally, students should be able to combine and categorize questions into 3-5 larger categories of questions to investigate.

Conferring Prompts

Confer with students as they create and categorize questions

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

Differentiation Point

Students have had multiple opportunities to develop a DQB at the beginning of previous units. Ideally students should be able to generate relevant questions about the phenomenon, but if students are struggling, encourage students to ask “how” or “why” questions, or provide them with a few sentence stems to get them started.

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

5. Ask students to think about investigations they could do or data they would need to answer their questions. Have them turn and talk to a partner before asking them to share out with the class. As they share, record their ideas on a piece of chart paper titled, “Ideas for Investigations.” If students struggle to come up with ideas, have them focus on just one cluster of questions or even one question to share ideas about.

Standards in Unit Opening

Performance Expectations

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)	ESS2.D Weather and Climate • Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. ESS2.D(3) ESS3.B Natural Hazards • Natural hazards and other geologic events have shaped the course of human history; they have significantly altered the sizes of human populations and have driven human migrations. ESS3.B(1)	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. CCC2(1)

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task
Developing and Using Models	*Tell the Story* *Performance Task Introduction* *Initial Model*	*Initial Model*	
ESS2.D Weather and Climate		*Initial Model*	
ESS3.B Natural Hazards	*Tell the Story* *Performance Task Introduction* *Initial Model*	*Initial Model*	
Cause and Effect	*Tell the Story* *Performance Task Introduction* *Initial Model*	*Initial Model*	

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task
Mathematics			
ELA/Literacy			

# Seasons Optional 3E	How does the annual cycle of the Earth around the sun create seasonal temperature variations?	**Performance Expectations** HS-ESS1-7	**Investigative Phenomenon** The Earth experiences seasonal temperature variations, and different parts of the planet experience different seasons at different times.	**Time** 3 days

In this optional 3E instructional sequence, aligned to the NYSED PE HS-ESS1-7, students are investigating how solar radiation reaches Earth at angles, causing seasonal differences depending on the relative position of the Earth compared to the sun. They discover that seasons are due to the difference in insolation reaching Earth because of Earth's tilt, and explain why different locations on Earth experience seasons at different times of year.

ENGAGE	What do students know about why we experience seasons?	The teacher learns what students know and care about related to **insolation and seasons** by asking students develop a **model of the Earth-Sun system** that **explains how and why** we experience seasons. Students become invested in the content and in their own learning. Doing this well saves time later on
EXPLORE	Students model angle of insolation and resulting temperature within the Earth-Sun system	Students learn about **differences in solar insolation across the Earth** by **collecting and graphing data** from two **angle of insolation** models and **identifying patterns in the data**. The teacher's role is to confer with students around their learning, but not offer formal explanations yet.
EXPLAIN	Students explain seasonal temperature patterns at various latitudes across the Earth	Students **use patterns** from the explore phase **to identify cause and effect relationships** in the Earth-Sun system in order to **explain why** **NYC and Melbourne are experiencing different seasons in June/July and Dec/Jan**. Students read a text and/or video about **insolation and seasons** in order to **revise their explanations** about the difference in Seasons in NYC and Melbourne and **construct a general explanation** for Seasons.
ELABORATE	This 3E has no Elaborate	
EVALUATE	This 3E has no Evaluate	

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

What do students know about why we experience seasons?

The teacher learns what students know and care about related to **insolation and seasons** by asking students develop a **model of the Earth-Sun system** that **explains how and why** we experience seasons. Students become invested in the content and in their own learning. Doing this well saves time later on

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Individual	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Why do we have seasons?	None	

Launch

1. Tell students that seasons, climate, and weather are distinct, but that they share some similarities.
2. Ask students to work in table groups to brainstorm how they think weather and climate might be similar and different. Use the group learning routine **Domino Discover** to surface student ideas

Look & Listen For

Possible student ideas:
- Climate is patterns of weather over long periods of time
- Weather is things like rain, temperature
- We have different weather during different seasons, and the temperature changes
- Seasons repeat annually

3. Tell students that they will begin this unit by investigating seasons in order to understand how the relationship of the Earth and the Sun contribute to different weather conditions, like temperature. When they are clear on that, they will be able to apply those same ideas to the new context of weather over long periods of time

Routine

The routine **Domino Discover** is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation. Refer to the Earth & Space Science Course Guide for support with this routine

Surfacing Student Ideas

1. Provide students with the handout Why do we have seasons? Give students time to individually respond to the prompt.

2. Teacher sets up the group learning routine **RUMORS** to elicit student ideas. Students use this group learning routine to voice and exchange their ideas about seasons.

Say:

"Let's share some ideas about the why we experience seasons. On a Post-It note, write down the statement that you are most confident about and explain your thinking."

Students write down one statement from the probe and an explanation of their thinking.

Then say:

"Now it is your job to share your rumor with as many people as you can in one minute. You must SAY your rumor out loud to a partner, LISTEN as they read you their rumor, and then EXCHANGE your Post-It with them. When you share with your next partner, you will share the rumor IN YOUR HAND, not your original rumor. Ready...go!"

3. Once students have spent one minute sharing their rumors, collect and sort rumors based on their similarities. You may choose to discuss the rumors now, or to leave all rumors up for the duration of this 5E, returning periodically to see if student ideas have changed over the course of the lessons.

4. Reflect on student ideas and plan forward based on student understandings, incomplete ideas, and misconceptions.

Access for All Learners

All students have some background knowledge on the topic of the Earth's orbit, the Sun, and temperatures on Earth, including scientific ideas from Unit 1: Discovering New Worlds 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.

Explore

Students model angle of insolation and resulting temperature within the Earth-Sun system

Students learn about **differences in solar insolation across the Earth** by **collecting and graphing data** from two **angle of insolation** models and **identifying patterns in the data**. The teacher's role is to confer with students around their learning, but not offer formal explanations yet.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❑ What causes seasons? Part 1: Using Physical Models ❑ Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation ❑ What causes seasons? Part 2. Using Computational and Visual Models ❑ Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation	❑ Heat lamp ❑ Inflatable globe ❑ 3 thermometers ❑ Tape ❑ Large square grid paper ❑ Markers ❑ Stopwatch	❑ Seasons and Ecliptic

Investigation Launch

1. Remind students of their questions regarding how Earth's position with respect to the Sun changes and how those changes impact seasons

2. Ask students what changes in Earth's position with respect to the Sun they think play a role in seasons

Look & Listen For

Possible student ideas:

- The distance from the Sun
- The Earth's tilt
- Earth's rotation

3. Let students know they will now have the opportunity to investigate how some of these factors impact sunlight hitting our position on Earth

What Causes Seasons Investigation Part 1 - Using Physical Models

1. Provide students with the handout, *What causes seasons? Part 1: Using Physical Models* and their supplies. Have them work table groups to create their models of the sun and earth.

2. Confer with students as they work in groups to enact the models and analyze their observations

Conferring Prompts

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

Part A

- Where on the globe is the temperature highest and where is it lowest?

Part B

- Where is the light most spread? Where is it least spread?
- How do you think the spread of light affects the heating of the Earth's surface?

Part C

- How did the angle of the Sun's rays change throughout the year? How do you think this relates to seasons?
- How did the Earth's revolution around the Sun affect its position in relation to the Sun?

Whole Class Investigation Summary

1. Once students have completed the investigation, provide students with the handout *Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation.* Have students complete the See-Think-Wonder.

2. Ask groups to decide on one important observation, idea and / or question from the See-Think-Wonder or analysis question to share with the whole class, from their discussion.

3. Use the **Domino Discover** group learning routine to surface important observations, inferences, and questions from groups.

What Causes Seasons Investigation Part 2 - Using Computational and Visual Models

1. Provide students with the handout *What causes seasons? Part 2. Using Computational and Visual Models*. Have students work in table groups to analyze the data and use the seasons and ecliptic simulator.

2. Confer with students as they work

Conferring Prompts

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

Part D

- **How is sunlight affecting different parts of the world?**
- **Are all areas of the globe receiving the same amount of light?**
- **How do you think the difference in light affects each area?**

phase-step: Whole Class Investigation Summary]

4. Once students have completed the investigation, provide students with the handout *Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation.* Have students complete the See-Think-Wonder.

5. Ask groups to decide on one important observation, idea and / or question from the See-Think-Wonder or analysis question to share with the whole class, from their discussion.

6. Use the **Domino Discover** group learning routine to surface important observations, inferences, and questions from groups.

Explain

Students explain seasonal temperature patterns at various latitudes across the Earth

Students **use patterns** from the explore phase **to identify cause and effect relationships** in the Earth-Sun system in order to **explain why NYC and Melbourne are experiencing different seasons in June/July and Dec/Jan**. Students read a text and/or video about **insolation and seasons** in order to **revise their explanations** about the difference in Seasons in NYC and Melbourne and **construct a general explanation** for Seasons.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs ❑ Table Groups	❑ Idea Carousel ❑ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❑ What Causes Seasons on Earth? ❑ What Causes Seasons on Earth?	None	❑ Poster paper ❑ Markers and colored pencils ❑ Class Consensus Discussion Steps ❑ The Seasons ❑ Insolation Part 2a- Reasons for the Seasons

Launch

1. Tell students that they will now construct an explanation, based on the models, data, and diagrams, about how seasons are formed.

2. Ask for students to share some of their initial ideas from the Explore about how the Earth's position could affect seasonality.

Constructing Explanations

1. Put students into pairs and have them respond to 'question 1' and 'question 2' on the first two pages of the Student Explain Guide.

2. Have students read the text, *The Seasons,* and/or watch the video, *Reason for the Seasons*, while taking notes in the student notetaker around the following:
- Ideas from the text or video that confirm their thinking about the reason there are seasons.
- Ideas from the text or video that contradict their thinking about the reason there are seasons.

- Ideas from the text or video that they have questions about.

Solicit students ideas and questions from their notes about the video and/or text. Lead direct instruction around formal terms for the concepts students have been exploring.

3. Put students in groups of 3-4 to collaboratively complete a poster version of their response to ‘Question 3’ on the third page of the Student Explain Guide.

4. Use the Group Learning Routine, Idea Carousel, to help students articulate and share their ideas.

Class Consensus Discussion

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

*We have a lot of different ideas circulating in the room right now. It is really important for us to get to some agreement on how Earth's position creates seasons, so we have a shared understanding to build on as we move forward. In order to do this, we are going to have a **Class Consensus Discussion**. First, I will select a few different groups to share their ideas and models. Then, we will let each group share their claim and models and discuss what we can agree on as a class.*

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

3. Post a piece or two of chart paper in front of the classroom and label it “Class Consensus Ideas: Seasons.” You will be recording student ideas on this paper as they surface during presentations. 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 Earth's tilt influences how much sunlight is reaching different areas of the globe, contributing to seasonality. 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.

4. While students are presenting, be sure to post the graph of glacial-interglacial cycles for them to reference as they explain their posters.

5. 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.

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

7. Before table groups confer, prompt them to consider the strength of the models. Some prompts you might provide are:

What evidence do you have for your explanation?
What is the mechanism for what you are claiming? What are the science ideas involved?
How confident do you feel about your claims? Why?

8. Resume the whole class discussion and, as the class agrees on important ideas or clear ways to represent their ideas, add them to the Class Consensus Chart.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit and the course. 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

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.

9. After all student ideas are captured on the class consensus list, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). Having questions at this point is fine and you should expect some to be there.

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

Take Time for These Key Points

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

- Sunlight provides heat for Earth
- Places that are receiving more direct sunlight become hotter than places receiving less direct sunlight
- The planet's tilt means that the northern hemisphere is tilted away from the sun for half the year, which is when the northern hemisphere is colder and the days are shorter. This is the northern hemisphere winter.
- At that same time, the southern hemisphere is tilted towards the sun, making the days longer and the temperature warmer. This is the southern hemisphere summer.
- For the other half of the year, the northern hemisphere is tilted towards the sun, meaning its days are longer and it gets warmer. This is northern hemisphere summer
- During that time, the southern hemisphere is tilted away from the sun, making it colder and with shorter days. This is the southern hemisphere winter

Note: *As the class comes to agreement on these ideas, summarize them on the Class Consensus Model. If there is still some disagreement, add that to the class model or mark it with a question mark (?). Ask the class to offer reasoning for the ideas. The question mark can also mean a student doesn't quite understand all the reasoning. These question marks will be the navigation in the next activity.*

11. Tell students that very different mechanisms are controlling global temperature and climate patterns over long periods of time, but that the relationship of the sun and earth, and how much radiation is reaching earth, is still a key component. Tell them that now they will move into an investigation about how changes in Earth's orbit over long periods of time influence climate at larger timescales.

12. Provide students with the handout *Summary Task*. This is an opportunity to individually, formatively assess students on their grasp of the 3 dimensions used in this phase.

Elaborate

This 3E has no Elaborate

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Evaluate

This 3E has no Evaluate

Preparation

Student Grouping	Routines	Literacy Strategies
None	None	None

Materials

Handouts	Lab Supplies	Other Resources
None	None	

Standards in Seasons Optional 3E

Performance Expectations

HS-ESS1-7	Clarification Statement: Assessment Boundary:

This PE, added by NYS, is not in the NGSS: Construct an explanation using evidence to support the claim that the phases of the moon, eclipses, tides and seasons change cyclically. [Clarification Statement: Emphasis of the explanation should include how the relative positions of the moon in its orbit, Earth, and the Sun cause different phases, types of eclipses or strength of tides. Examples of evidence could include various representations of relative positions of the Sun, Earth and moon.] [Assessment Boundary: Assessment does not include mathematical computations to support explanations but rather relies on conceptual modeling using diagrams to show how celestial bodies interact to create these cyclical changes.]

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2)	ESS1.B Earth and the Solar System • Earth and celestial phenomena can be described by principles of relative motion and perspective. ESS1.B(3)NYS	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)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Constructing Explanations and Designing Solutions	*Why do we have seasons?*	*What causes seasons? Part 1: Using Physical Models* *Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation* *What causes seasons? Part 2. Using Computational and Visual Models* *Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation*	*What Causes Seasons on Earth?* *What Causes Seasons on Earth?*		
ESS1.B Earth and the Solar System	*Why do we have seasons?*	*What causes seasons? Part 1: Using Physical Models* *Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation* *What causes seasons? Part 2. Using Computational and Visual Models* *Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation*	*What Causes Seasons on Earth?* *What Causes Seasons on Earth?*		

	Engage	Explore	Explain	Elaborate	Evaluate
Patterns	*Why do we have seasons?*	*What causes seasons? Part 1: Using Physical Models* *Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation* *What causes seasons? Part 2. Using Computational and Visual Models* *Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation*	*What Causes Seasons on Earth?* *What Causes Seasons on Earth?*		

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		MP2 MP3 MP4 MP6	MP2 MP3 MP4 MP6		
ELA/Literacy		WHST.9-10.9	WHST.9-10.9		

Earth-Sun Dynamics 5E	What factors have contributed to climate change in the past and are they contributing to climate change now?	**Performance Expectations** HS-ESS2-4	**Investigative Phenomenon** The amount of radiation received at 65°N has gone up and down over the last 750,000 years and repeats a pattern about every 100,000 years.	**Time** 5 days

In this 5E instructional sequence, students are investigating the questions about Earth's position relative to the Sun in the past and present that surfaced during the Driving Question Board launch, such as *How do we know that natural cycles aren't causing climate change today? How has the Earth's position with respect to the Sun changed over time? How does the Earth's changing position with respect to the Sun affect temperatures on Earth?* Students develop and use models to analyze and interpret orbital cycle data to arrive at conclusions about what role Earth's position with respect to the Sun may have played in past climate change events and what role it is having today.

ENGAGE	How has the amount of radiation (sunlight) reaching Earth varied in the past?	Connecting to their earlier questions about how Earth's temperature has varied in the past, students **analyze and interpret** the **total amount of energy** from **solar radiation reaching Earth at 65° N** over the last 750,000 years by **using a mathematical model (graph)**.
EXPLORE	How does Earth's position affect the amount of radiation reaching Earth's surface?	Students **use models** of **Earth's eccentricity, tilt, and direction of tilt** cycles to collect **empirical evidence** in order to determine whether there is a **causal relationship** between **orbital cycles and the amount of solar radiation reaching Earth at 65° N** over the last 750,000 years.
EXPLAIN	Did changes in Earth's position cause the patterns of radiation reaching Earth's surface and glacial-interglacial cycles?	Students **use their models to analyze and interpret data in order to make claims** about whether **variations in Earth's position with respect to the Sun (Milankovitch Cycles)** are causing the **total amount of energy** from **solar radiation reaching Earth at 65° N** as well as **glacial-interglacial cycles**.
ELABORATE	How well does activity from the Sun correlate with glacial-interglacial cycles?	Students **evaluate evidence** for the **causal relationship** between **changes in the amount of radiation from the Sun** and **the glacial-interglacial cycles**.
EVALUATE	How do we know that orbital factors are not causing climate change today?	Students **analyze data about the current orbital factors and solar cycles to explain** the role **cyclic factors** play in **causing** climate change today.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How has the amount of radiation (sunlight) reaching Earth varied in the past?

Connecting to their earlier questions about how Earth's temperature has varied in the past, students **analyze and interpret** the **total amount of energy** from **solar radiation reaching Earth at 65° N** over the last 750,000 years by **using a mathematical model (graph)**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Pairs	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Radiation and Temperature During Earth's Past	None	❏ Map of Greenland ❏ Northern Hemisphere Ice Coverage Over 400,000 years ❏ The Rise and Fall of Ice Age Glaciers

Launch

1. Remind students that during the Driving Question Board launch, one category of questions and ideas to investigate that emerged was related to variation in the amount of sunlight / radiation reaching Earth in the past, such as: *How do we know that climate change isn't happening because of natural cycles? How has the amount of radiation (sunlight) reaching Earth varied in the past? Does the amount of radiation (sunlight) that the Sun produces vary over time? Did these natural factors contribute to temperature changes during Earth's past? Do they contribute to global warming today?*

2. Tell students that scientists have been able to collect data from ice cores, tree rings, and ocean sediments located at high latitudes to determine Earth's temperature as far back as 800,000 years ago at those locations. And they have used similar data along with mathematical models to determine how much solar insolation was reaching Earth over that same time period.

3. Show students the world map to locate Greenland, one of the locations data is collected from, and play the video Northern Hemisphere Ice Coverage Over 400,000 years so they have a visual of how changing temperatures at high latitudes affect ice coverage on Earth.

4. Ask students what they notice about the ice over time. Listen for them to say it increases and decreases in a pattern. Let students know that they are going to have an opportunity to investigate their questions about whether the amount of solar radiation reaching Earth in the past has varied and if it

contributes to temperature changes on Earth, as well as the increase and decrease in ice they observed.

5. Help students explain why we are focused on summertime only at 65 N. Remind them that ice sheets, which are key in glacial cycles, form at higher latitudes, and that scientists have discovered a strong correlation between summer insolation at this latitude and glacial-interglacial cycles.

6. Provide students with the handout, *Radiation and Temperature During Earth's Past*, and display the graph. In pairs or table groups, have students use the See-Think-Wonder graphic organizer to make sense of the graph.

Surfacing Student Ideas

1. Have pairs or small groups confer and decide which observation, idea, and question from their See-Think-Wonder they think is most important to share with the class.

2. Use the **Domino Discover** group learning routine, to facilitate students sharing their ideas and questions as a class.

Look & Listen For

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

- I see a pattern of the total amount of insolation reaching Earth at 65° N rising and falling over time.
- The cycles of the total amount of insolation reaching Earth at 65° N changes on a scale of thousands of years.
- I see a pattern in the glacial and interglacial periods changing over time
- When the insolation is highest, the Earth is in interglacial periods
- The total amount of insolation reaching Earth at 65° N is at its lowest point about every 100 thousand years with some exceptions.
- There are some peaks about half way between the larger peaks.
- While there are general repeating patterns, there are also a lot of irregularities.
- It looks like there is a relationship between insolation and glacial periods
- I think Earth's position with respect to the Sun can impact the total amount of radiation reaching Earth at 65° N.
- I think the amount of energy (radiation) the Sun emits can impact the total amount of radiation reaching Earth at 65° N.
- How does the amount of insolation change?
- How does the amount of insolation affect glacial and interglacial periods? Why aren't they perfectly aligned?

3. Students are likely to have a range of ideas and questions, but are likely to name Earth's position with respect to the Sun and output from the Sun as factors that can impact the total amount of radiation reaching Earth at 65° N. Leverage those ideas and let them know that they will have the opportunity to work with models in order to understand how Earth's changing position and the Sun's output affect the total amount of radiation reaching Earth at 65° N, and then see if what they learn can help them

Classroom Supports

Create a poster or space on a whiteboard for student ideas and questions that surface. Use the title *How has Earth's temperature varied in the past?*

Access for All Learners

All students have some background knowledge on the topic of the Earth's orbit, the Sun, and temperatures on Earth, including scientific ideas from Unit 1: Discovering New Worlds 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.

determine whether these factors have contributed to changes in temperature they observed during the unit launch.

4. Before moving on, open a conversation about the word “correlation.” Tell students that they are observing a correlation between glacial-interglacial cycles and insolation, because there seems to be a relationship between when they rise and fall. Ask students if they know the difference between “correlation” and “causation.” After a discussion about each of these words, ask students what evidence they would need in order to be able to say that there is a causative relationship between these factors.

Routine

This is the first time **Domino Discover** is being used in this unit. This routine is an opportunity to surface students’ thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation. Refer to the Earth & Space Science Course Guide for support with this routine

Integrating Three Dimensions

This Engage is designed to support students in thinking about **CCC #2 - Cause and Effect**. In this learning sequence, students will need to use empirical evidence to distinguish between causation and correlation, a key component of Cause and Effect at the High School Level. Take time to ensure that students are comfortable using each of those words and the differences between the two.

Explore

How does Earth's position affect the amount of radiation reaching Earth's surface?

Students **use models** of **Earth's eccentricity, tilt, and direction of tilt** cycles to collect **empirical evidence** in order to determine whether there is a **causal relationship** between **orbital cycles and the amount of solar radiation reaching Earth at 65° N** over the last 750,000 years.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❑ Orbital Factors Investigation ❑ Making Sense of the Orbital Factors Investigation	❑ Small flashlight ❑ Sphere or globe 6 inches in diameter ❑ markers / pen / pencil	❑ The direction of Earth's tilt with respect to the Sun

Investigation Launch

1. Remind students of their questions regarding how Earth's position with respect to the Sun changes and what impact those changes have on the total amount of radiation reaching Earth at 65° N and average global temperatures throughout Earth's history that they observed during the unit launch.

2. Ask students what changes in Earth's position with respect to the Sun they think could have had or can have on temperatures on Earth.

Look & Listen For

Possible student ideas:
- The distance from the Sun
- The Earth's tilt
- Earth's rotation
- The amount of radiation coming from the Sun

3. Let students know they will now have the opportunity to investigate how some of these factors impact the radiation reaching Earth's surface.

Variation in Earth's Position Investigation

1. Provide students with the handout, *Orbital Factors Investigation.* Have them work in pairs to model each factor of the orbit to see its effect on the Earth. Provide support with figuring out how to model each factor as needed.

2. Confer with students as they work in groups to enact the models and analyze their observations

Conferring Prompts

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

- What are the two extremes of the cycle?
- Do you think these changes impact the total amount of radiation reaching Earth at 65° N?
- Do these changes during the cycle affect the radiation reaching Earth the same everywhere on Earth or does it affect radiation in some places more than others?

Differentiation Point

If a group is struggling with developing any of the models, ask questions to support them in thinking about how to model different points in each of the orbital cycles such as: *How would you model when the Earth is further away from the Sun vs closer to the Sun? How can we observe the difference in how much of the radiation from the Sun (flashlight) is reaching Earth's surface in these different scenarios?* You may also consider pausing the class after about 5-10 minutes for different groups to share how they are modeling the orbital cycles so groups can adopt ideas from each other.

Access for All Learners

Some students may struggle to make sense of how the changes in Earth's position with respect to the Sun will impact radiation reaching Earth. Be sure to provide all students with access to manipulatives that can be used to model different scenarios.

Whole Class Investigation Summary

1. Once students have completed the investigation, provide students with the handout *Making Sense of the Orbital Factors Investigation*. Have students complete the See-Think-Wonder and answer the analysis question.

2. Ask groups to decide on one important observation, idea and / or question from the See-Think-Wonder or analysis question to share with the whole class, from their discussion.

3. Use the **Domino Discover** group learning routine to surface important observations, inferences, and questions from groups.

Routine

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

Look & Listen For

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

- Earth's orbit goes through a 100,000 year cycle between nearly circular and more oval like, affecting how close the Earth is to the Sun at different times of a year.
- Our models showed that when Earth is closer to the Sun it receives a higher proportion of radiation from the Sun.
- I think if it receives more radiation it will make the temperature on Earth higher.
- When the Earth is further from the Sun it gets less radiation and that will make it cooler.
- Earth's degree of tilt (axis) with respect to the Sun goes through a 41,000 year cycle between a 22.1 and 24.9 degree tilt, which affects the angle of insolation and concentration of radiation on Earth at different latitudes, including at 65° N.
- The direction of Earth's tilt with respect to the Sun goes through a 26,000 year cycle. At one extreme of the cycle the Earth's northern hemisphere is tilted toward the Sun when the Earth is closest to the Sun. At the other extreme, Earth's northern hemisphere is tilted away from the Sun when the Earth is closest to the Sun.
- I think this has an impact on the angle and concentration of radiation that reaches Earth at different latitudes, including at 65° N.
- How much does each of these changes impact radiation reaching Earth at different latitudes?
- How much does each of these changes impact temperatures on Earth?
- What was happening with Earth's position with respect to the Sun in the past?
- What is happening with Earth's position with respect to the Sun recently?

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

Explain

Did changes in Earth's position cause the patterns of radiation reaching Earth's surface and glacial-interglacial cycles?

Students **use their models to analyze and interpret data in order to make claims** about whether **variations in Earth's position with respect to the Sun (Milankovitch Cycles)** are causing the **total amount of energy** from **solar radiation reaching Earth at 65° N** as well as **glacial-interglacial cycles**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Groups of 2-3 students	❑ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Orbital Factors and Glacial Cycles Part 1 ❑ Orbital Factors and Glacial Cycles Part 2 ❑ Summary Task	None	❑ Poster paper ❑ Markers and colored pencils ❑ Class Consensus Discussion Steps ❑ *Sample Class Energy Budget Model After Earth-Sun Dynamics* ❑ The Vostok Core and Milankovitch Cycles

Launch

1. Ask a few volunteers to share about the data they explored in the last class. Also ask, *What questions were we trying to answer with the data?* Students explored data related to the Earth's position and how that might change the amount of radiation that reaches Earth at 65°N. Remind students why we are studying areas that are at 65°N.

2. Ask for students to share some of their initial ideas from the Explore about how the Earth's position related to the Sun could affect the amount of radiation that reaches the Earth at 65°N.

3. Direct students to the task by saying: *We used different models to investigate whether changes in the position of the Earth with respect to the Sun could explain changes in the amount of radiation coming to Earth from the Sun. For that, we will apply our models and understanding to different scenarios. Then we will use this understanding to see if they explain real changes in data.*

Explanatory Models

1. Facilitate a class discussion around features of a good explanatory model. 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.

<u>Features of a good explanatory model</u>
Models are used to represent a system (or parts of a system) under study.
Explanatory models:
- illustrate and/or predict the relationships between systems or between components of a system.
- Utilize scientific vocabulary and labels
- Provide a scientific mechanism for what you are claiming through the model
- Are based on real data

Look & Listen For

Students may generate a range of ideas.
- Models should contain representations of real world objects or ideas
- illustrate and/or predict the relationships between systems or between components of a system.
- Utilize scientific vocabulary and labels
- Provide a scientific mechanism for what you are claiming through the model

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

2. Let students know that they will use and develop models to analyze data about how Earth's orbital factors were changing over specific periods of time. They will then compare their models to a computational model of that data to figure out the role of orbital factors in creating glacial-interglacial cycles.

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.

Integrating Three Dimensions

This investigation provides an opportunity to engage with **SEP #2 - Developing and Using Models**. Students may not have an understanding that scientific models are based on real data. Be sure to unpack this enough so that students know the model they create will be based on evidence. This is particularly important, because they will be using data generated from this model to make evidence-based claims.

Developing and Using Models of Orbital Factors During Climatic Changes

1. Provide students with the handout, *Orbital Factors and Glacial Cycles Part 1*. Ask them to complete parts 1 in groups of 2-3.

Implementation Tip

In part 1 of this activity, students are explaining how changes in orbital factors result in different amounts of insolation reaching Earth. The models they are engaging with are scaffolded to increase in complexity throughout the task. In the first example, they are responsible for determining how the orbital factors would influence sunlight in northern hemisphere summers using fully drawn models. In the third example, they have to use data describing the orbital positions to complete the visual model and then analyze the impact on summer.

2. Put students in groups of 3-4, and tell them to take turns sharing ideas from their models and explanations to develop a group model on poster paper. Their group model should explain the mechanism of how Earth's changing position with respect to how the Sun affects the melting and freezing of ice sheets in each of the three timeframes observed in part 1. Use the conferring questions to support students in developing their models.

Conferring Prompts

Suggested conferring questions:
These questions should support and push students' thinking about how they are using their model to provide a mechanistic account of how Earth's changing position with respect to the Sun affects the melting and freezing of ice sheets.

- What is happening to the total amount of radiation reaching Earth?
    - How are you representing that on your model?
- What is happening to the total amount of radiation reaching Earth at 65° N?
    - How are you representing that on your model?
- What is happening to the amount of radiation reaching the ice sheets?
    - How does your model help you explain this?
- What impact will changes in radiation you're depicting have on ice sheets?
- What evidence and science concepts support your claim?

3. Tell students that they will now have the opportunity to use a computational model to better observe the correlation between orbital factors and glacial-interglacial cycles.
4. Provide students with the handout *Orbital Factors and Glacial Cycles Part 1*. Have them work in their original groups of 2-3 to complete that section, including the summary questions.
5. Have students turn back to their larger table groups and give them an opportunity to revise their explanatory models.
6. Have groups post their explanatory models around the room.

Integrating Three Dimensions

Students are working toward proficiency in **using a model to provide a mechanistic account of phenomena**, an important element of **SEP #2 - Developing and Using Models** at the HS level. The suggested conferring questions are meant to push students toward clearly illustrating a mechanistic account for the phenomenon depicted by the glacial interglacial graph. Mechanistic accounts will also be an important consideration later, when students evaluate the strength of causal relationships in their claims.

Class Consensus Discussion

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

*We have a lot of different ideas circulating in the room right now, and they are in the form of different explanatory models you have developed. It is really important for us to get to some agreement on how we represent what we know about how Earth's varying position with respect to the Sun and how that impacts the total radiation reaching Earth at 65° N and glacial-interglacial cycles, so we have a shared understanding to build on as we move forward. In order to do this, we are going to have a **Class Consensus Discussion**. First, I will select a few different groups to share their ideas and models. Then, we will let each group share their claim and models and discuss what we can agree on as a class.*

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

3. Post a piece or two of chart paper in front of the classroom and label it "Class Consensus Ideas: Earth's Position and Changing Ice Sheets." You will be recording student ideas on this paper as they surface during presentations.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 Earth's varying position with respect to the Sun impacts the radiation reaching Earth and glacial-interglacial cycles. 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.

4. While students are presenting, be sure to post the graph of glacial-interglacial cycles for them to reference as they explain their posters.

5. 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.

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

Routine

Class Consensus Discussions are so important for the Explain phase across this unit and the course. 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.

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #2 - Cause and Effect** explicit for students by elevating and probing for ideas related to the concept that **empirical evidence is required to make claims about specific causes and effects.**

Class Consensus Discussion Steps

1. We listen to 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.
7. We agree or disagree (and tell why) with the ideas or offer revision ideas.

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.

7. Before table groups confer, prompt them to consider the strength of the models. Some prompts you might provide are:

What evidence do you have for your model?
What is the mechanism for what you are claiming? What are the science ideas involved?
How confident do you feel about your claims? Why?
How would each factor impact energy reaching Earth, considering both input and distribution?

8. Resume the whole class discussion and, as the class agrees on important ideas or clear ways to represent their ideas, add them to the Class Consensus Chart.

9. After all student ideas are captured on the class consensus list, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). Having questions at this point is fine and you should expect some to be there.

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

Implementation Tip

Tip: We recommend you do NOT just let students read their explanatory model students will be developing aloud. Some classmates will need to see/read the explanatory model students will be developing 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**:

- 130 kya Earth was closer to the Sun and more tilted toward the Sun during the northern hemisphere Summer than it was 150 kya.
  - This would have caused there to be more summer radiation reaching Earth and the concentration of radiation reaching Earth at 65° N to increase.
  - This would have increased temperature at 65° N like we saw during that time frame in the glacial-interglacial cycles, shifting the Earth to an interglacial period.
- Between 130 kya and 113 kya the direction of Earth's tilt changed, so it was a lot further to the Sun during the northern hemisphere Summer. The degree of tilt toward the Sun decreased during the same time period as well. The distance between Earth at different points in its orbit changed very little.
  - This would have caused there to be less total radiation reaching Earth and the concentration of radiation reaching Earth at 65° N to decrease.
  - This would have decreased temperature at 65° N like we saw during that time frame in the glacial-interglacial cycles, shifting the Earth to an glacial period.
- Between 25 kya and 9 kya the degree of earth's tilt toward the Sun increased.
  - This would have caused the concentration of radiation reaching Earth at 65° N to increase.
  - This would have increased temperature at 65° N like we saw during that time frame in the glacial-interglacial cycles, shifting the Earth to an glacial period.

Note: *As the class comes to agreement on these ideas, summarize them on the Class Consensus Model. If there is still some disagreement, add that to the class model or mark it with a question mark (?). Ask the class to offer reasoning for the ideas. The question mark can also mean a student doesn't quite understand all the reasoning. These question marks will be the navigation in the next activity.*

11. Post an additional piece of chart paper in the front of the room and label it "Class Consensus Model: Global Energy Budget"

Note: you will return to this Model throughout the unit to add complexity as students gain further information about energy inputs and outputs on Earth in future 5Es. The goal of this chart will be to construct a global energy budget model including elements from each 5E moving forward.
An example is included in *Sample Class Energy Budget Model After Earth-Sun Dynamics*

12. On the "Class Consensus Model: Global Energy Budget," use ideas from the consensus discussion to construct an overall model of the combined impact of orbital factors on the amount of energy reaching Earth. Leave space in this model; the class will be adding impacts of ice caps, oceans, and greenhouse gases to the model over time.

13. Then point out to students that they have not considered whether the output from the Sun could have contributed to the glacial-interglacial cycles. Ask them why it might be important to determine how much the different orbital forcing factors (eccentricity, direction of tilt, and degree of tilt) contributed to the glacial-interglacial cycles and whether output from the Sun contributed to the glacial-interglacial cycles.

Look & Listen For

Possible student ideas:

- It will help us strengthen our claims if we can explain which factors contribute most.
- There are parts of the glacial-interglacial cycles we have not explained, so maybe other factors like the Sun's output can help us.
- It would not be a complete explanation / or model if we do not consider those questions.

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

15. The results of this task can be used to make determinations about which students need more time to circle back to the ideas in this text in the coming parts of the 5E lesson.

Implementation Tip

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

16. Tell students they will now have an opportunity to explore the varying impact of eccentricity, direction of tilt, and degree of tilt as well as the output of radiation from the Sun.

Elaborate

How well does activity from the Sun correlate with glacial-interglacial cycles?

Students **evaluate evidence** for the **causal relationship** between **changes in the amount of radiation from the Sun** and **the glacial-interglacial cycles**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Pairs	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Solar Cycles	None	

Launch

1. Remind students that last time they wanted to further investigate another idea they had about variables that influence climate was about the amount of radiation the Sun is emitting. Ask students what data they want to look at in order to collect evidence that will support claims about whether the Sun's total emitted radiation was a factor that contributed to past climate change events. If students have ideas that relate to radiation from the Sun already posted on the Ideas for Investigations chart from the Unit Launch, use those initial ideas to help students think of additional ideas for investigations.

Look & Listen For

Possible student ideas:

- We want to see data that shows us if and how the total amount of radiation emitted by the Sun has changed over time.
- We want to compare this data to temperature changes on Earth
- It would be helpful to see this data as a visual like a graph
- We should look for patterns or cycles and see at what rate the Sun's output of radiation has changed and compare the direction and rate of those changes to the direction and changes in Earth's temperature.

Implementation Tip

This task is an opportunity to continue developing an understanding of the idea that **empirical evidence is needed to distinguish between correlation and causation,** an important high school element of **CCC #2 - Cause and Effect.** A key part of making claims about causality is to consider other variables that could potentially explain a phenomenon. Here students are investigating whether output from the Sun can help to explain solar radiation reaching Earth at 65° N as well as glacial-interglacial cycles.

2. Let them know that the NASA has been investigating this same question and has produced graphs of the amount of radiation the Sun has emitted over time by using isotope proxies in the same way oxygen isotopes were used to infer the Earth's temperature in the past, as well as data collected through instruments since the 1960's.

Making Claims about the Causal Relationship Between the Sun's Total output and Global Temperature Changes

1. Provide students with the handout, *Solar Cycles* Have them work independently or in pairs to analyze and interpret the 2 graphs of the Sun's total irradiance vs average global temperatures over time, and use what they observe to complete the See-Think-Wonder that follows.

Conferring Prompts

Confer with students as they work to analyze and interpret the graph and complete the See-Think-Wonder table.

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

- What patterns do you notice in the data? Are there any apparent cycles in the data? What is your empirical evidence?
- What is the time scale of any cycles you're seeing?
- What was happening to the total amount of radiation emitted from the Sun around the time of the climate change event you're investigating?
- Does the direction of the trend in global temperatures seem to indicate that the Sun's total radiation output may have contributed to temperature changes around the time of the climate change event you're investigating?
- Does the scale of time of changes in the Sun's total radiation output vs scale of temperature changes seem to indicate that Sun's total radiation output contributes to temperature changes around the time of the climate change event you're investigating?

2. Have students work independently or in pairs to view the images and graphs and respond to the questions. They should end by responding to the question: :
    - Did the Sun's total output contribute to the climate change event you're investigating? What is your evidence and scientific reasoning?

Access for Multilingual 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.

Look & Listen For

Possible student ideas:

- There are cycles that last about 10-11 years; that scale of time does not match the scale of time (10s and 100s of thousand years) during which the glacial-interglacial occurred.
- I think the total amount of radiation from the Sun does impact temperature on Earth because radiation is energy that can heat the Earth.
- At times, increasing sunspot activity is correlated with increasing temperatures, but at other times, they are not correlated
- Orbital factors may contribute more strongly to Earth's temperature than solar activity

Evaluate

How do we know that orbital factors are not causing climate change today?

Students **analyze data about the current orbital factors and solar cycles to explain** the role **cyclic factors** play in **causing** climate change today.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Individual	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Revisiting the Performance Task: Earth-Sun Dynamics 5E ❏ The Sun and Current Climate Change - Performance Task Data ❏ Earth-Sun Dynamics Rubric	None	

Return to the Performance Task

1. Remind students that their task is to disprove skeptics who claim that climate change is happening because of natural causes like changing orbital factors or solar cycles.

2. Provide them with the handout *The Sun and Current Climate Change - Performance Task Data.* Students can work in small groups or individually to analyze the data, which they will then use to complete the performance task.

3. Have students work individually to complete the explanation in the *Revisiting the Performance Task: Earth-Sun Dynamics 5E*.

2. Confer with students while they are working.

Conferring Prompts

Confer with students as they work to develop models and explanations. Prompt students to return to the class wide correlation to causation spectrum checklist questions as they develop and evaluate claims.

Suggested conferring questions:

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

Revisiting the Temperature Data and Driving Question Board

1. Return to the Tell the Story documents and the Driving Question Board. Ask students to discuss what questions have been answered and what still remains.

2. Conduct a **Domino Discover** to hear from each group

Look & Listen For

Possible student ideas:

- We explained past climate change events on a scale of 10 and 100s of thousands of years, but we have not explained why sun-earth dynamics do not fully explain glacial-interglacial cycles
- We have determined that sun-earth dynamics are not causing the changes in temperature that we are seeing now
- We haven't determined what is causing climate change now

3. Ask students what they think might be causing climate change, based on their prior knowledge. Students are likely to say that they think humans and/or greenhouse gases are likely playing a role. Leverage that prior knowledge to transition into the next 5E.

Performance Expectations

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

In NYS the clarification statement has been edited as follows: Examples of the causes of climate change could include those that differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation, solar output; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition and plate tectonic.

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Use a model to provide mechanistic accounts of phenomena. SEP2(5) Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. SEP4(1)	ESS1.B Earth and the Solar System • Cyclical changes in the shape of Earth's orbit around the Sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of Sunlight falling on the Earth. These phenomena cause a cycle of ice ages and other gradual climate changes. ESS1.B(2) ESS2.A Earth Materials and Systems • The geologic record shows that changes to global and regional climate can be caused by interactions among changes in the Sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. ESS2.A(3) ESS2.D Weather and Climate • The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. ESS2.D(1) ESS2.E Biogeology • The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. ESS2.E(1)	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. CCC2(1) Energy and Matter • The total amount of energy and matter in closed systems is conserved. CCC5(1)

Assessment Matrix

	Engage	Explore	Explain	Elaborate	Evaluate
Developing and Using Models		*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*	*Solar Cycles*	*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
Analyzing and Interpreting Data	*Radiation and Temperature During Earth's Past*	*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*		*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
ESS1.B Earth and the Solar System		*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*		*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
ESS2.A Earth Materials and Systems	*Radiation and Temperature During Earth's Past*	*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*		*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
ESS2.D Weather and Climate	*Radiation and Temperature During Earth's Past*	*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*		*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
ESS2.E Biogeology				*Solar Cycles*	
Cause and Effect	*Radiation and Temperature During Earth's Past*	*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*	*Solar Cycles*	*Revisiting the Performance Task: Earth-Sun Dynamics 5E*
Energy and Matter	*Radiation and Temperature During Earth's Past*	*Orbital Factors Investigation* *Making Sense of the Orbital Factors Investigation*	*Orbital Factors and Glacial Cycles Part 1* *Orbital Factors and Glacial Cycles Part 2* *Summary Task*		*Revisiting the Performance Task: Earth-Sun Dynamics 5E*

Common Core State Standards Connections

	Engage	Explore	Explain	Elaborate	Evaluate
Mathematics		MP2 MP3 MP4 MP6	MP2 MP3 MP4 MP6		
ELA/Literacy		WHST.9-10.9	WHST.9-10.9	WHST.9-10.1 WHST.9-10.5 SL.9-10.4	WHST.9-10.1 WHST.9-10.9

Student Work for Earth-Sun Dynamics 5E

Example Student Work Revisiting the Performance Task: Earth-Sun Dynamics 5E

Disproving climate skeptics

Using the data about historical temperature changes over time, the changes in orbital factors over the past 9,000 years, the solar cycles, and the effect of solar factors on energy entering Earth's systems, make and support a valid claim about the role of orbital factors and solar cycles on the melting of ice caps today.

Orbital factors and solar cycles are not contributing to the melting of ice caps today.

Since 9 thousand years ago, both the eccentricity and tilt of Earth has decreased. The decreasing tilt means that when the northern hemisphere is tilted towards the sun, it is angled less sharply than it was 9 thousand years ago, and therefore is receiving less solar radiation during the northern hemisphere summer than it was before. That change would lead to cooling of the northern hemisphere and increasing ice caps.

Additionally, Earth's precession has changed so that the northern hemisphere is tilted away from the sun when Earth is closer to it, and is tilted towards the sun when Earth is further away. Because Earth is further away during the northern hemisphere summer, the northern hemisphere is receiving less summer solar radiation than it was 9kya, when Earth was closer to the sun while it was tilted towards it. The result of these three orbital factors means that Earth should be cooler compared to 9kya and glaciers should be expanding towards a glacial period, not shrinking.

Furthermore, the scale of time that the orbital factors operate on does not match the rate of warming seen in this warming event. When orbital factors cause glacial-interglacial cycles, temperature changes take thousands of years to occur. We have warmed much faster than that, over only a few hundred years.

Solar cycles also cannot account for the current moment of climate change. Solar cycles last approximately 11 years, and the overall intensity of solar radiation has been decreasing over the last 50 years. Over that same period of time, average global temperatures have been increasing.

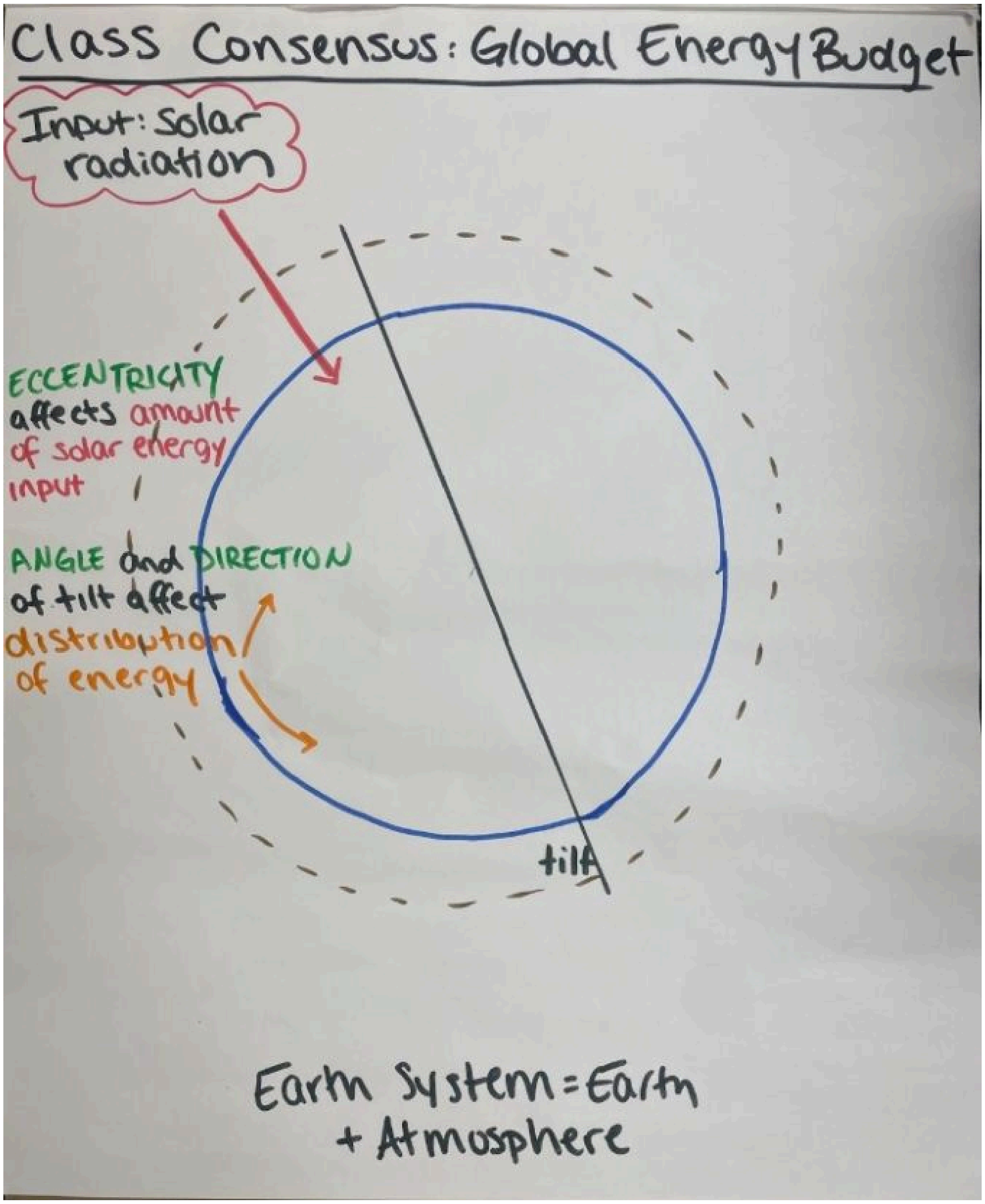
For there to be a causal relationship between orbital factors/solar cycles and warming temperatures, there would have to be a correlation between the time scales, predicted effects of those factors, and the change in temperature. There is not a correlation between those things: instead of cooling, we are warming. Though not all examples of correlation mean causation, there can be no causation without correlation. These factors are not contributing to climate change today.

Classroom Resources for Earth-Sun Dynamics 5E

Sample Class Energy Budget Model After Earth-Sun Dynamics

Sample Class Energy Budget Model After Earth-Sun Dynamics

Sample Class Consensus Model: Global Energy Budget After Earth-Sun Dynamics



Climate Feedbacks 5E	What is causing global temperatures to rise, and why is the Arctic warming at almost 4 times the rate as the rest of the globe?	**Performance Expectations** HS-ESS2-2, HS-ESS2-4, HS-ESS2-6	**Investigative Phenomenon** The globe is warming, and the average temperature of the Arctic is increasing at almost 4 times the rate as the rest of the globe.	**Time** 7-9 days

Driven by student questions about current climate change not explained by orbital factors and ideas about greenhouse gases and glacial cycles, students investigate how feedback mechanisms increase or decrease changes, stabilizing or destabilizing climate systems and altering Earth's temperatures.

ENGAGE	What is happening to temperatures and Arctic ice today?	Students **use a graph to analyze data** of **changes in temperature in the Arctic compared to the rest of the globe** to discuss **climate change**.
EXPLORE 1	How do carbon dioxide levels in the air both impact and change as a result of Earth's systems?	Students **develop and use models** to gather **evidence about the causal mechanism behind the correlation** between atmospheric **carbon dioxide levels and climate factors like temperature**.
EXPLAIN 1	How are atmospheric carbon dioxide levels and temperatures related?	Students **construct an explanation using empirical evidence** from data, models, and text, describing how **human activities** have **caused** greenhouse gas levels to increase and their impact on climate.
EXPLORE 2	How is the icy surface of the poles changing?	Students **analyze models and datasets** of **surfaces on Earth** in order to figure out how different surfaces **change the surrounding system** and impact **temperature on Earth**.
EXPLAIN 2	Why is the Arctic warming at almost 4 times the rate as the rest of the planet?	Students **construct an explanation** for how **positive feedback loops** related to **albedo effect** are currently causing the **Arctic to warm at twice the rate of the rest of the planet**.
ELABORATE	How do greenhouse gases and albedo interact?	Students **model** the combined effects of **greenhouse gas and albedo feedback loops** to **explain the rapid rate of change** of Earth's temperature and make c**laims about what could happen** in the future based on historical and current evidence.
EVALUATE	How can we use what we learned to explain the impacts human activities are having on Earth's systems?	Students **analyze data to make a valid claim** about the role **human activities** are playing in **causing destabilizing feedback loops** that cause **climate change**.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

What is happening to temperatures and Arctic ice today?

Students **use a graph to analyze data** of **changes in temperature in the Arctic compared to the rest of the globe** to discuss **climate change**.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Rumors	None

Materials

Handouts	Lab Supplies	Other Resources
❏ We are Warming	None	❏ Driving Question Board ❏ Ideas for Investigations Chart ❏ As Arctic warms, Indigenous communities there face dramatic changes to their way of life

Launch and Surfacing Student Ideas

1. Gather students around the DQB and ask for a volunteer to remind the class what questions we had at the end of the last investigation.

2. Remind students that we know from the Unit Launch that global temperatures are increasing, despite the Milankovitch cycles indicating that we should be in a cooling period. Tell the class that you are going to zoom in to see how much warming has happened over a shorter time period of the last several decades to see if that helps us understand what could be causing climate change today.

3. Provide students with the handout *We are Warming* and show them the video As Arctic warms, Indigenous communities there face dramatic changes to their way of life .

4. Give students time to individually analyze the graph and brainstorm their ideas using prior knowledge in response to the prompt: Since we know this isn't due to orbital factors, what do you think is causing warming, and why is the rate of warming not consistent across the planet?

5. Use the routine *Domino Discover* to surface patterns in student responses.

Routine

The **Domino Discover** routine is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation. Refer to the Earth & Space Science Course Guide for support with this routine.

Look & Listen For

Possible student ideas:

- Greenhouse gases are related to warming
- Carbon dioxide is related to warming
- Human activities are related to warming
- Ice melting makes the arctic warm faster

Explore 1

How do carbon dioxide levels in the air both impact and change as a result of Earth's systems?

Students **develop and use models** to gather **evidence about the causal mechanism behind the correlation** between atmospheric **carbon dioxide levels and climate factors like temperature**.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❏ Carbon Dioxide and Air Temperature Investigation ❏ Making sense of the Carbon Dioxide and Air Temperature Investigation	❏ Calculator	❏ Greenhouse Effect

Launch

1. Remind students that many had an idea that greenhouse gases and/or carbon dioxide were causing climate change. Tell them that they will be investigating the relationship between air temperature and greenhouse gases to understand how there might be a causal relationship between the two.

Carbon Dioxide and Air Temperature Investigation

1. Provide each student with a copy of the *Carbon Dioxide and Air Temperature Investigation* handout

2. Before students begin, take a moment to surface high level observations of the atmospheric carbon dioxide and temperature change graphs at the beginning of Part 1. Ask students what they notice about the graphs

Look & Listen For

Possible student ideas and questions:
- There is a correlation between atmospheric carbon dioxide and air temperature change
- When carbon dioxide levels increase, so do air temperatures, and vice versa

Integrating Three Dimensions

In this unit students will develop proficiency related to **CCC#7 Stability and Change**: **rates of change**. The Conferring Prompts and the prompts in the See-Think-Wonder organizer are meant to help students begin to develop this concept.

3. Emphasize for students that they are observing a correlation. Ask students what information they would need in order to determine a causal mechanism that explains the correlation.

4. Have students work in table groups on parts 1 of the investigation. Use conferring questions to push students' thinking about the investigation while they are collecting data.

5. Pause students when they are done with part 1. Support students in identifying that the dramatic change in the rise of carbon dioxide happened during an event called the Industrial Revolution. Tell students that they will get a chance to see what happened during the Industrial Revolution and how it caused atmospheric carbon dioxide levels to increase so dramatically.

6. Have students work through part 2. Confer with them as they conduct their investigation.

Conferring Prompts

Confer with students during the investigation. Suggested during-lab conferring questions:
- What do you notice about the stability of the carbon cycle pre and post industrial revolution?
- How does the movement of carbon change after the industrial revolution?
- What reservoirs have more carbon after the industrial revolution?
- How does your model of the carbon cycle change after the industrial revolution?

7. When groups are done, ask students to consider the prompt: how did the carbon cycle change after the industrial revolution compared to before?

8. Use the routine *Domino Discover* to surface important observations about the investigation so far

Look & Listen For

Possible student ideas and questions:
- The amount of carbon moving from fossil fuels to the atmosphere increased
- The amount of carbon moving from the atmosphere to all other systems increased
- There is more carbon dioxide in every system except the geosphere
- The system is not in balance anymore

9. Tell students that they will now investigate what those rising levels of carbon dioxide do in the atmosphere by using a simulation.

10. Have students work in table groups to complete Part 3 of the investigation using the Greenhouse Effect simulation. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

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

- Where is the energy coming from?
- How does the energy change as it interacts with the surface of the Earth?
- How does the energy react as greenhouse gas levels rise?

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the handout *Making sense of the Carbon Dioxide and Air Temperature Investigation*
2. Have groups discuss their responses and then come up with one important idea they noted or question that arose to share with the whole class, from their discussion.
3. Use the **Domino Discover** group learning routine to surface important trends, inferences, and questions from groups.

Look & Listen For

Possible student ideas and questions:

- Sunlight comes to Earth
- Some sunlight that hits ice or clouds is bounced back into space
- Heat leaves earth
- Some of that heat goes out into space
- Greenhouse gases bounce heat back to Earth
- When there are more greenhouse gases in the atmosphere, more heat turns back to Earth

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.
5. Ask students if they think their results transfer to the real world:
    - What implications do their results have for different surface types on Earth?
    - How might ice, land, and water all interact with radiation differently?
    - Are there any additional factors that might make their results less applicable to the real world?
6. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence

Routine

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

Access for Multilingual Learners

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

Explain 1

How are atmospheric carbon dioxide levels and temperatures related?

Students **construct an explanation using empirical evidence** from data, models, and text, describing how **human activities** have **caused** greenhouse gas levels to increase and their impact on climate.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Independent ❏ Pairs ❏ Table groups	❏ Think-Talk-Open Exchange ❏ Class Consensus Discussion	❏ Text Annotation

Materials

Handouts	Lab Supplies	Other Resources
❏ The Enhanced Greenhouse Effect ❏ The Greenhouse Effect Text ❏ Burning Fossil Fuels Text ❏ Summary Task	None	❏ Class Consensus Discussion Steps ❏ Chart paper ❏ From the first 5E: Global Consensus Model: Global Energy Budget ❏ Evidence Links Human Activity to Global Warming | Decoding the Weather Machine

Launch

1. Tell students that they will now have an opportunity to figure out the connections between the industrial revolution, changes in atmospheric greenhouse gas levels, and climate change

2. Provide students with *The Enhanced Greenhouse Effect*. Have students work in triads to complete Part 1 of the handout by analyzing the sources of atmospheric CO_2 in the air today.

3. When students are done, pause the class to discuss how scientists know the sources of CO_2 in the atmosphere. Show the video Evidence Links Human Activity to Global Warming | Decoding the Weather Machine

4. Tell students that they will read a few texts in order to determine the cause and effect mechanisms taking place that result in warming temperatures from increased anthropogenic carbon dioxide.

Supporting a Scientific Claim

1. Arrange students in triads. Give each student the *The Greenhouse Effect Text* and the *Burning Fossil Fuels Text* and have them read and annotate the texts using the following annotation strategy:
    a. Checkmark ideas that connect to or confirm your current ideas
    b. Circle ideas that help answer a question you had
    c. Write a question mark next to ideas that you are unclear of and would like to discuss with classmates.
2. When students are done reading, have them independently turn to Part 2 of their *The Enhanced Greenhouse Effect* handout and brainstorm their ideas in response to question 1.
3. Facilitate the group learning routine think-talk-open exchange. Then have students record additional ideas they gained from their conversations.
4. Prompt students to work independently to outline their Claim, Evidence, and Reasoning in response to the prompt: What is the relationship between human activities and temperature increase since the industrial revolution?

Conferring Prompts

Confer with students while they develop their models. Suggested conferring questions:

- What evidence are you using in support of your claim?
- Where did the evidence come from?
- Is there any additional evidence that can support your claim?
- How does the evidence connect to your claim?
- What logical reasoning connects the evidence to your claim?

Routine

This is the first time the routine **Think-Talk-Open Exchange** appears in this unit! During this routine, students share with others and gain feedback on their ideas by finding similarities and differences, piecing together disparate bits of information, or reconciling different interpretations. Overall, the routine allows students to clarify or generate ideas collaboratively. Please consult the Earth and Space Science Course Guide for detailed steps about this routine.

Integrating Three Dimensions

This C-E-R is designed to support students in using empirical evidence to make claims about causes and effects, **an important high school level element of CCC #2 - Cause and Effect**. Use conferring questions to push students toward the idea that empirical evidence about the changes in carbon dioxide levels and the mechanism of the greenhouse effect give support to a causal relationship between the industrial revolution and climate change.

Class Consensus Discussion

1. Provide table groups with chart paper. Have them discuss their claims and construct a joint C-E-R table containing their combined evidence and reasoning

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

*We have a lot of different ideas circulating in the room right now. It is really important for us to reach some agreement so that we can be sure that the industrial revolution has caused climate change at this moment in time. In order to do this, we are going to have 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 model and discuss what we can agree on as a class.*

3. You may decide to walk students through the entire poster of the Class Consensus Steps or take them through the steps as you facilitate it.

4. Post a piece or two of chart paper in front of the room and title it, *Class Consensus: How Human Activities Cause Climate Change*. You will be recording student ideas on this paper as they surface during presentations.

5. 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 Earth's varying position with respect to the Sun impacts the radiation reaching Earth and glacial-interglacial cycles. 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.

6. 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.

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

Routine

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

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #7 - Stability and Change** explicit for students by elevating and probing for ideas related to the idea of **change and rates of change**, an important element of cause and effect at the high school level.

Class Consensus Discussion Steps

1. We listen to 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.
7. We agree or disagree (and tell why) with the ideas or offer revision ideas.

8. After all ideas are captured on the class consensus list, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). Having questions at this point is fine and you should expect some to be there.

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

Take Time for These Key Points

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

- Historical evidence tells us that the industrial revolution occurred in around 1850, and included burning fossil fuels
- Empirical evidence tells us that atmospheric carbon dioxide levels have increased since that time
- Scientists have confirmed that the rise in atmospheric carbon dioxide is anthropogenic
- The mechanism of the greenhouse effect demonstrates how carbon dioxide increases the amount of energy retained in Earth's atmosphere
- There is a clear cause and effect relationship between these human activities and climate change

10. When the class feels satisfied, add the key summary information to the *Class Consensus Model: Global Energy Budget* from the previous 5E. Students will now have a developing model showing how orbital factors and solar output modify energy entering the Earth system, and how the greenhouse effect alters the amount of energy exiting the system.

Summary Task

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.

Implementation Tip

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

Explore 2

How is the icy surface of the poles changing?

Students **analyze models and datasets** of **surfaces on Earth** in order to figure out how different surfaces **change the surrounding system** and impact **temperature on Earth**.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❑ Ice and Radiation ❑ Making Sense of the Ice and Radiation Investigation	❑ 4 cups or jars ❑ Green blue black and white construction paper ❑ 4 thermometers ❑ Tape ❑ Scissors ❑ Timer ❑ Heat lamp	❑ Sea Ice Extent Since 1980 ❑ Documenting Glacial Change | PBS LearningMedia ❑ How to make a line graph in Google Sheets ❑ How hot is asphalt or cement in summertime?

Launch

1. Revisit student ideas and questions regarding why the arctic is warming four times faster than the rest of the world. Remind students that they had the idea that ice interacts differently with heat or light than other areas.

2. Ask students if they gained any additional information from the previous investigation that could help them understand what is happening at the poles. Students may recall that the *Greenhouse Effect* simulation demonstrated sunlight reflecting when it hits clouds or ice.

3. Ask students why they think ice reflects radiation or interacts with radiation from the Sun in different ways than other surfaces and what questions they have about this. Prompt students to consider how “bright” different surfaces are, and how that impacts the way they experience light and heat in those areas. Good examples include people getting sunburned on a ski trip or in shaded areas near oceans and lakes.

Look & Listen For

Possible student ideas:

- Ice is white and I remember learning that white or lighter colors reflect radiation more than darker surfaces.
- Seawater and land is darker than ice, so those surfaces must reflect less radiation.
- Does a surface heat less when it reflects more radiation?
- Does a surface heat more when it reflects less radiation?
- What impact does more or less reflection of radiation have on other Earth's systems?

4. Provide each student with a copy of the *Ice and Radiation* handout and ask students what they notice about the two images. Highlight responses that identify the color differences between the two.

5. Tell students that they will now have the chance to develop a model that can be used to test their ideas and questions about how ice, land, seawater, and various surfaces of different colors interact with radiation and what impact more or less reflection of radiation by ice has on other Earth systems.

How Ice Interacts with Radiation Investigation

1. This lesson is best done on a sunny day, when you can walk outside with the class to directly observe how radiation affects different surfaces. If you are unable to go outside, watch the video *How Hot is Asphalt or Cement in Summertime?* instead of proceeding with steps 2-4. Students can answer the same prompts indicated in step 5 in the handout.

2. Have students turn back to their *Ice and Radiation* handout and start with Part 1.

3. Take the thermometers and stopwatches (don't distribute yet)—and ask students to take their science notebooks and pencil—and go to an area near black asphalt, where there is also another observable surface or two, such as lightly-colored concrete and/or a lawn receiving the same amount of sunlight.

4. Ask the students to work in table groups to explore the area for a couple of minutes. Encourage them to stand on the different surfaces and compare the temperatures at each surface. They can even use their hands to feel the surface. They do not need to measure the temperature at this time, just note relative differences. Use the conferring prompts below to support students in making relevant observations.

Conferring Prompts

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

- What do you observe about the different surfaces?
- Which surface(s) feel warmer? Why?
- How do you think the temperature of these surfaces impacts the air above them?

5. Tell students that they should record their observations in writing in their handout. Circulate to answer any questions.

6. After a minute or two, ask a couple of the partners to share their ideas. Discuss how asphalt and other dark surfaces heat up quickly in direct sunlight.

Look & Listen For

Possible student ideas and questions:

- The black asphalt is much hotter than the white or yellow lines painted on it even though they are receiving the same amount of radiation.
- The black asphalt is also hotter than the white cement even though they are receiving the same amount of radiation.
- There is a pattern: the lightest surfaces were the coolest, and the darkest surfaces were the hottest

7. Tell students they will now have the opportunity to work in their groups to design a more reliable experiment to investigate how radiation interacts with different surfaces on Earth. Use the previous conversation to help students segue from testing the impact of ice on radiation to testing the impact of color on the heat of surfaces and air around them. Have them turn to Part 2 in their copy of the *Ice and Radiation* handout.

8. Provide students with their materials and assist students as they set up their experiment. Each cup should be fully covered with a different color of paper with a hole in the top to place a thermometer through. The thermometer should be positioned so that it can be read above the paper.

9. Support students as they conduct the experiment. Use conferring questions to push students' thinking about the investigation while they are collecting data.

Conferring Prompts

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

- Which colored surfaces increased the most in temperature?
- Which colored surfaces increased the least in temperature?
- What patterns do you notice about increases in temperature?

10. When students are done with Part 2, pause the class to discuss their findings. Students should have observed that darker colors absorbed more heat, while lighter colors warmed less. Ask students how they think that might relate to the real world ice caps.

Look & Listen For

Possible student ideas and questions:

- Maybe ice heats up less than land/reflects light away from land
- If ice melts, maybe the dark land around it heats up more

11. Tell students that they will now apply what they saw in their models to real-world data in order to better understand what is happening in the arctic.

12. Show students the images in Documenting Glacial Change | PBS LearningMedia . As students to describe what they see happening in the images. Highlight the extent of change happening to the glaciers, and also the visible darkening of these regions.
13. Have students work in pairs to complete Part 3 of the investigation. Support students in constructing line graphs from the data tables. They should be constructing four line graphs, showing how each variable has changed over time. It is important that students don't try to plot them all on the same graph because the scales of each will not allow for the clear visualization of each data set.

Differentiation Point

If students need additional support with constructing line graphs, show them a video like How to make a line graph in Google Sheets .

14. Support students as they analyze the graphs to determine relationships between the variables described.

Differentiation Point

If students are interested in going into more depth with data analysis, help students place best fit lines on the graph using google sheets. Students can play with which types of fit lines match the data most closely: linear, exponential, or logarithmic. Open a discussion about what linear or exponential change means. If students are interested, they can try to forecast how these variables will continue to change by following the trend lines.

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the handout *Making Sense of the Ice and Radiation Investigation*, then use the completed pages to discuss the questions that follow.
2. Ask groups to come up with one important idea they noted or question that arose to share with the whole class, from their discussion.
3. Use the **Domino Discover** group learning routine to surface important trends, inferences, and questions from groups.

Look & Listen For

Possible student ideas and questions:

- Darker colors heat up more than lighter colors
- When temperatures rise, ice melts
- As ice melts, dark surfaces are revealed, which heat more than the ice heats

4. If students don't surface any of the important observations named in the Look and Listen For, direct students back to appropriate investigation resources and use conferring questions to support them in making those observations before moving on, as they will be key to success in the Explain phase that follows.
5. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence

Routine

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

Access for Multilingual Learners

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

Explain 2

Why is the Arctic warming at almost 4 times the rate as the rest of the planet?

Students **construct an explanation** for how **positive feedback loops** related to **albedo effect** are currently causing the **Arctic to warm at twice the rate of the rest of the planet**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Independent ❑ Pairs ❑ Table groups	❑ Class Consensus Discussion	❑ Cause-and-Effect Chart

Materials

Handouts	Lab Supplies	Other Resources
❑ Ice Caps and Global Temperatures ❑ Summary Task	None	❑ Class Consensus Discussion Steps ❑ Chart paper ❑ From the last investigation: Class Consensus Model: Global Energy Budget ❑ The Rise and Fall of Ice Age Glaciers ❑ Earth's Albedo and Global Warming | PBS LearningMedia

Launch

1. Tell students that they will have an opportunity to explain the relationship between temperature, ice, and color.

2. Introduce students to the word "albedo" and "the albedo effect" to explain how ice reflects sunlight. For useful visuals, project the resource Earth's Albedo and Global Warming | PBS LearningMedia , and show students the "introduction" and "ice-albedo feedback" tabs.

3. Ask students to describe the albedo effect in their own words, and have a few students share out.

Look & Listen For

- Light-colored surfaces return a large part of the sun rays back to the atmosphere (high albedo).
- Dark surfaces absorb the rays from the sun (low albedo).
- Ice- and snow-covered areas have high albedo, and an ice-covered Arctic reflects solar radiation which otherwise would be absorbed by the oceans and cause the Earth's surface to heat up.

4. Tell students that they will have the opportunity to incorporate these ideas and explore their questions as they develop a model that explains why the Arctic is warming at almost four times the rate as the rest of the planet.

Developing a Cause and Effect Model Model for the Rapid Rate of Warming in the Arctic

1. Provide students with the handout *Ice Caps and Global Temperatures* and the *Ice Caps Cause and Effect Cards*, and piece of paper for arranging the cards on. Note: the cards should end up showing a feedback loop, so students should not end with linear cause and effect models.

2. Confer with students as they develop their models.

Conferring Prompts

Confer with students while they develop their models. Suggested conferring questions:

- Which cards are the causes of other cards?
- What mechanisms explain the changes shown on the cards?
- Which cards should be connected with arrows?
- How do these causes and effects combine to explain how the arctic is warming faster than the rest of the world?

3. Ask students to work in table groups to sort the cards and fill in the missing causes/mechanisms. When they are done, students should independently summarize their work in the cause and effect model section of their handout.

4. Make sure that groups hold onto their work. They will be adding cards to this cause-and-effect sequence during the Elaborate phase.

5. Have students turn to the next section: revisiting the investigative phenomenon. Allow students to brainstorm ideas as a table, but then have students write their own responses individually.

Integrating Three Dimensions

The cause and effect sequences students are asked to complete are meant to surface the idea of **positive feedback loops that further destabilize the system, an important high school level element of CCC #7 - Stability and Change** . Use conferring questions to push students toward the idea that if ice expands, more radiation is reflected back into space, causing further cooling and more expansion of ice, and vice versa.

Class Consensus Discussion

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

We have a lot of different ideas circulating in the room right now, and they are in the form of different explanatory models you developed. It is really important for us to get to some agreement about how ice and other surfaces impact radiation reaching Earth, so we have a shared understanding to build on as we move ahead. In order to do this, we are going to have 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 model and discuss what we can agree on as a class.*

2. You may decide to walk students through the entire poster of the Class Consensus Steps or take them through the steps as you facilitate it.

3. Post a piece or two of chart paper in front of the room and title it, *Class Consensus: How Ice Impacts Radiation Reaching Earth*. You will be recording student ideas on this paper as they surface during presentations.

4. Select two or three groups' card sort models 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 Earth's varying position with respect to the Sun impacts the radiation reaching Earth and glacial-interglacial cycles. 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.

5. 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.

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

Class Consensus Discussion Steps

1. We listen to 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.
7. We agree or disagree (and tell why) with the ideas or offer revision ideas.

Routine

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

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #7 - Stability and Change** explicit for students by elevating and probing for ideas related to the idea of **positive feedback loops that further destabilize the system**, an important element of cause and effect at the high school level. .

7. Before table groups confer, prompt them to consider the role of feedback loops in figuring out which claim is best supported. Some prompts you might provide are:
    - What do you notice about the first and last boxes? How might you revise the model to make it clearer?
    - How does albedo affect energy in Earth's system, considering inputs, outputs, and distribution?
    - How do you think this phenomenon leads to rapid heating in the Arctic?
8. Resume the whole class discussion and as the class agrees on important ideas or clear ways to represent their ideas, add them to the Class Consensus.

9. After all ideas are captured on the class consensus list, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). Having questions at this point is fine and you should expect some to be there.

10. During the whole class discussion, there will be opportunities to identify important terms and concepts that emerge. Sometimes, important points may get buried in student talk. Use student ideas about how cooling leads to more ice, which leads to more cooling, and how heating leads to less ice, which leads to more heating, to introduce the phrase **positive feedback loop**. Let them know that they can use that term to describe situations where changes occur within systems and lead to more of the same changes within those systems.

Take Time for These Key Points

Pause the discussion and ask for clarification, particularly of the following key points:
- As ice melts in the Arctic, more dark surfaces are exposed.
- Darker surfaces reflect less radiation and absorb more radiation compared to the lighter ice surface that was there before.
- Because these darker surfaces absorb so much radiation, they heat up much faster than the ice did and also heat the air above them more than ice did.
- Since the air is now a higher temperature, it melts even more ice in the Arctic region.
- The cycle repeats over and over so that's why the Arctic region is heating up so much faster than the rest of the globe where not as much ice melts.
- Albedo increases the amount of energy leaving Earth's system by reflecting solar radiation away; melting ice decreases the amount of energy leaving the system by retaining it and converting it to heat energy
- Ice caps have a high albedo (or reflectivity) that reflects much more radiation from the Sun back into space when compared to sea water or land underneath it.
- There is a positive feedback loop. As ice caps melt and the amount of heat absorbed by earth's surface increases, more ice caps melt and the cycle continues, and as ice caps expand and the amount of heat absorbed by earth's surface decreases, the ice caps expand more and the cycle continues.

11. When the class feels satisfied with their model, add the key summary information to the *Class Consensus Model: Global Energy Budget* from the previous 5E. Students will now have a developing model showing how orbital factors and solar output modify energy entering the Earth system, and how albedo alters the amount of energy exiting the system.

12. Return to the question of why we focused on the northern hemisphere in the first 5E instead of the second 5E. Tell students that now we have enough information to answer why the northern hemisphere has a greater impact on global temperatures than the southern hemisphere does. Ask students if they

think water or land has the higher albedo. They should discuss that water has a higher albedo than land, because it is “brighter” and it reflects more light. Show them the video The Rise and Fall of Ice Age Glaciers . Ask students which hemisphere has more land, and which has more water. Prompt them to consider which hemisphere would absorb more radiation when the ice has melted. Help them conclude that the quantity of land present in the northern hemisphere increases the effect of melted ice from decreasing albedo.

13. Remind students that they still have not explained why the Earth experienced sudden cooling and heating as it transitioned out of the last glacial period. Let them know that they will be able to continue to investigate this further in the next part of this 5E lesson by investigating what happens when ice sheets melt at a rapid rate.

Summary Task

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.

Implementation Tip

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

Elaborate

How do greenhouse gases and albedo interact?

Students **model** the combined effects of **greenhouse gas and albedo feedback loops** to **explain the rapid rate of change** of Earth's temperature and make **claims about what could happen** in the future based on historical and current evidence.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Think-Talk-Open Exchange	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Greenhouse Gas Feedback Mechanisms	❑ Laptops	❑ Card sort made from *Ice Caps Cause and Effect Cards* ❑ *Greenhouse Gas Feedback Mechanisms* ❑ Chart paper

Modeling the Effect of Temperature on the Carbon Cycle

1. Pose the question: if the cause and effect mechanisms of human caused climate change are so clear, what evidence do climate skeptics use to say otherwise?
2. Tell students that as we consider that question, we will also consider the future of global warming and what types of effects it might have.
3. Provide each student with the handout, *Greenhouse Gas Feedback Mechanisms* and ask students to independently brainstorm how the graph at the top of the handout is different from the ones they've seen so far.
4. After students have had the opportunity to view the graph and generate ideas, ask a few students to share their ideas.

Routine

This is the first time the routine **Think-Talk-Open Exchange** appears in this unit! During this routine, students share with others and gain feedback on their ideas by finding similarities and differences, piecing together disparate bits of information, or reconciling different interpretations. Overall, the routine allows students to clarify or generate ideas collaboratively. Please consult the Earth and Space Science Course Guide for detailed steps about this routine.

Look & Listen For

Possible student ideas:

- Previously, we've seen an increase in carbon dioxide causing global temperatures and arctic temperatures to rise
- In this graph, we see antarctic temperatures rising first, then carbon dioxide levels, and then global temperatures

5. Tell students that this graph is something skeptics point to in order to claim that temperature changes are normal, and that the increase in carbon dioxide is an effect of warming, not the cause of it.

6. Have students work in triads to complete Part 1 of the handout.

7. When students are done, have students return to their Ice Caps Cause-and-Effect Card sort. Provide students with the *Greenhouse Gas Feedback Mechanisms*. Have students add the new cards, including adding the new mechanisms to the two additional cards.

8. When students are done, facilitate the group learning routine Think-Talk-Open Exchange as students complete Part 2 of the handout.

Evaluate

How can we use what we learned to explain the impacts human activities are having on Earth's systems?

Students **analyze data to make a valid claim** about the role **human activities** are playing in **causing destabilizing feedback loops** that cause **climate change**.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Small groups ❏ Individual	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Revisiting the Performance Task: Climate Feedbacks 5E ❏ Disprove the Skeptics ❏ Climate Feedbacks Rubric	None	❏ Chart Paper ❏ Sticky Notes

Revisit the Performance Task

1. Provide students with the handout *Disprove the Skeptics*. Students can work independently or in small groups to analyze the data shown.

2. Have students independently respond to the prompts in their performance task organizer.

2. Confer with students while they are working.

Conferring Prompts

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

Revisit the Driving Question Board

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

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

3. Add new questions to the Driving Question Board. Highlight for students that we now know how climate change has happened in the past and how it is happening now, but that we still don't know the impacts it might have on people. In other words, we haven't addressed any skeptic who says that climate change isn't a big deal.

Standards in Climate Feedbacks 5E

Performance Expectations

HS-ESS2-2 **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.**
Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.
Assessment Boundary: None

In NYS the clarification statement has been edited as follows: Examples of data could include descriptions of climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples of data could also include descriptions other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.

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

In NYS the clarification statement has been edited as follows: Examples of the causes of climate change could include those that differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation, solar output; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition and plate tectonic.

HS-ESS2-6 **Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.**
Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.
Assessment Boundary: None

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. SEP2(4) Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. SEP4(1)	ESS2.A Earth Materials and Systems • Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. ESS2.A(1) • The geologic record shows that changes to global and regional climate can be caused by interactions among changes in the Sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. ESS2.A(3) ESS2.D Weather and Climate • The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. ESS2.D(1)	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. CCC2(1) Energy and Matter • The total amount of energy and matter in closed systems is conserved. CCC5(1) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Developing and Using Models	*We are Warming*	*The Enhanced Greenhouse Effect Summary Task*	*Ice and Radiation* *Making Sense of the Ice and Radiation Investigation* *Ice Caps and Global Temperatures Summary Task*	*Greenhouse Gas Feedback Mechanisms*	
Analyzing and Interpreting Data		*Carbon Dioxide and Air Temperature Investigation* *Making sense of the Carbon Dioxide and Air Temperature Investigation*			*Revisiting the Performance Task: Climate Feedbacks 5E Disprove the Skeptics*
ESS2.A Earth Materials and Systems	*We are Warming*	*Carbon Dioxide and Air Temperature Investigation* *Making sense of the Carbon Dioxide and Air Temperature Investigation* *The Enhanced Greenhouse Effect Summary Task*	*Ice and Radiation* *Making Sense of the Ice and Radiation Investigation* *Ice Caps and Global Temperatures Summary Task*	*Greenhouse Gas Feedback Mechanisms*	*Revisiting the Performance Task: Climate Feedbacks 5E Disprove the Skeptics*
ESS2.D Weather and Climate	*We are Warming*	*Carbon Dioxide and Air Temperature Investigation* *Making sense of the Carbon Dioxide and Air Temperature Investigation* *The Enhanced Greenhouse Effect Summary Task*	*Ice and Radiation* *Making Sense of the Ice and Radiation Investigation* *Ice Caps and Global Temperatures Summary Task*	*Greenhouse Gas Feedback Mechanisms*	*Revisiting the Performance Task: Climate Feedbacks 5E Disprove the Skeptics*

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Cause and Effect		*Carbon Dioxide and Air Temperature Investigation* *Making sense of the Carbon Dioxide and Air Temperature Investigation* *The Enhanced Greenhouse Effect* *Summary Task*	*Ice and Radiation* *Making Sense of the Ice and Radiation Investigation* *Ice Caps and Global Temperatures* *Summary Task*	*Greenhouse Gas Feedback Mechanisms*	*Revisiting the Performance Task: Climate Feedbacks 5E* *Disprove the Skeptics*
Energy and Matter					*Revisiting the Performance Task: Climate Feedbacks 5E* *Disprove the Skeptics*
Stability and Change					*Revisiting the Performance Task: Climate Feedbacks 5E* *Disprove the Skeptics*

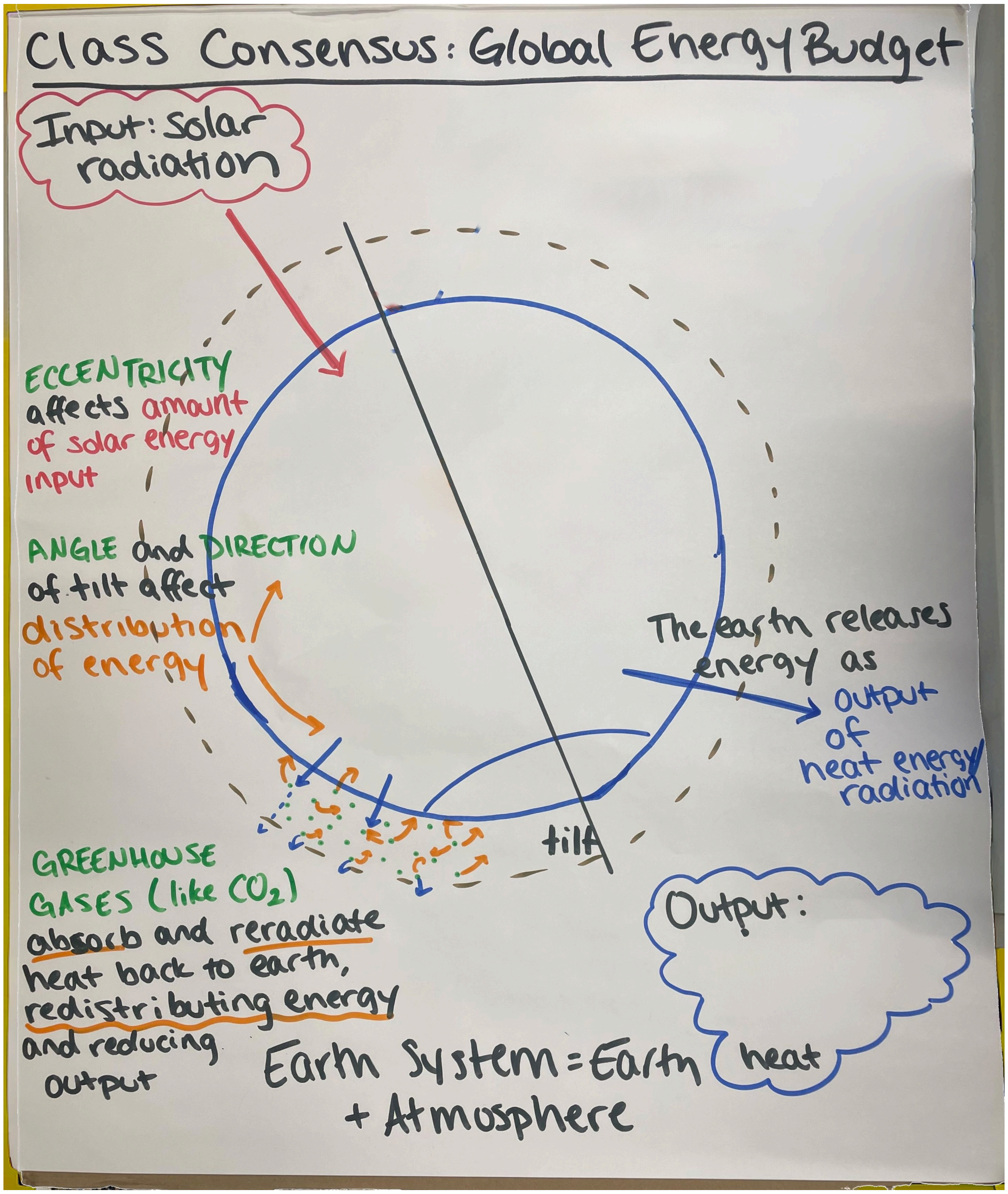
Common Core State Standards Connections

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP2 MP3 MP4 MP6	MP2 MP3 MP4 MP6		
ELA/Literacy		WHST.9-10.9	WHST.9-10.9	WHST.9-10.1 WHST.9-10.5 SL.9-10.4	WHST.9-10.1 WHST.9-10.9

Student Work for Climate Feedbacks 5E

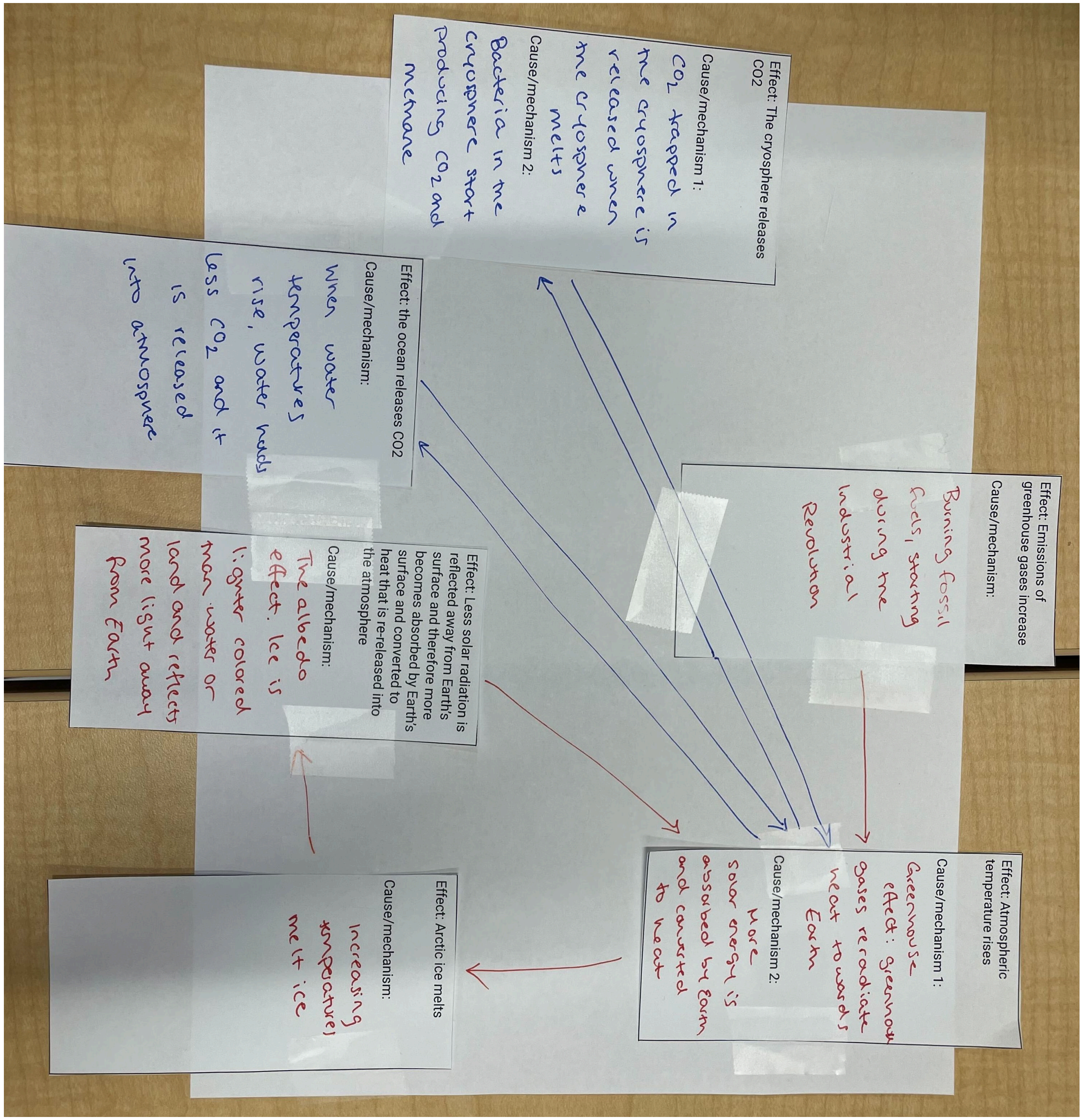
Sample Class Energy Budget Model After Greenhouse Gases

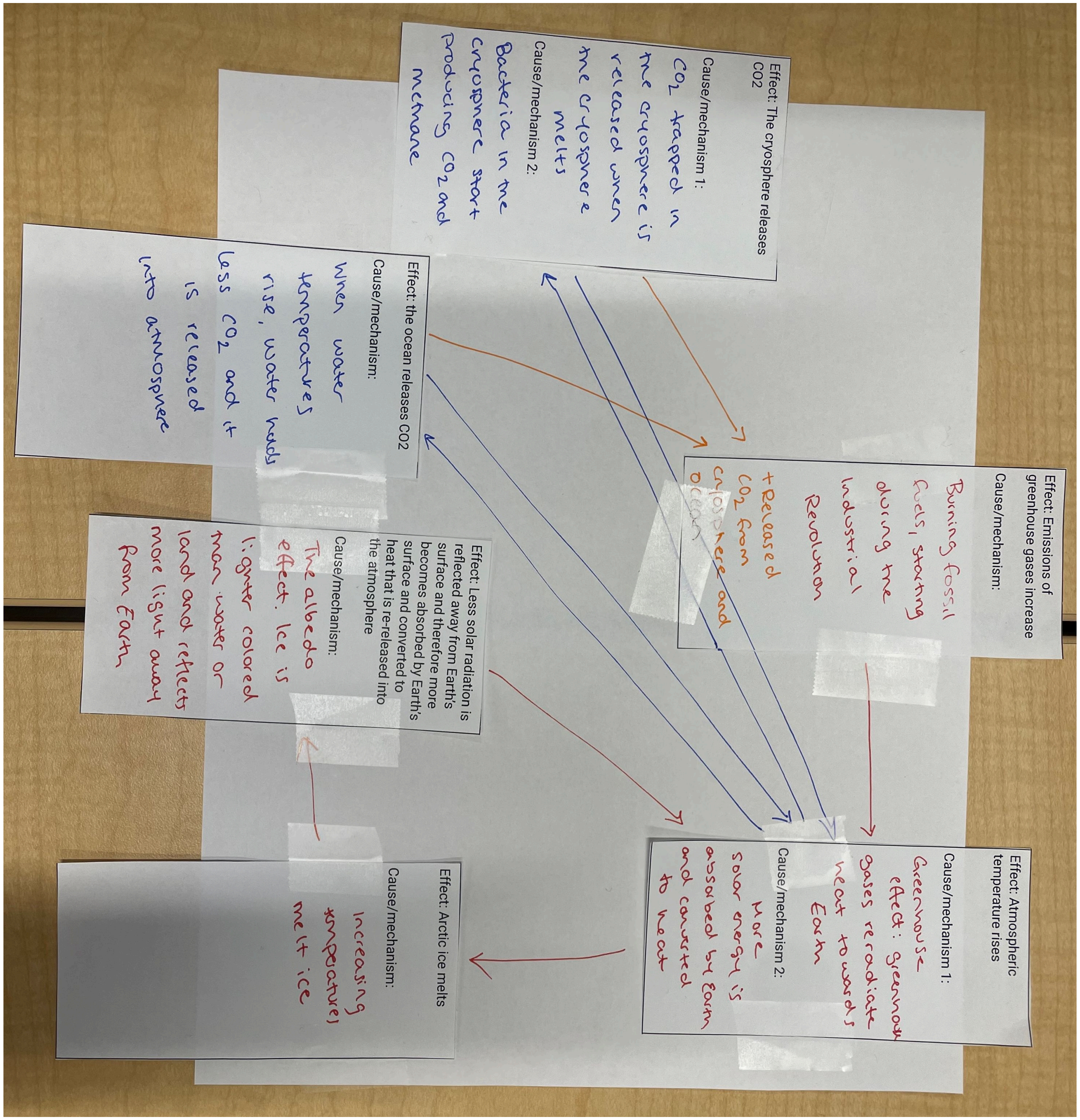
Sample Class Consensus Model: Global Energy Budget after Greenhouse Gases



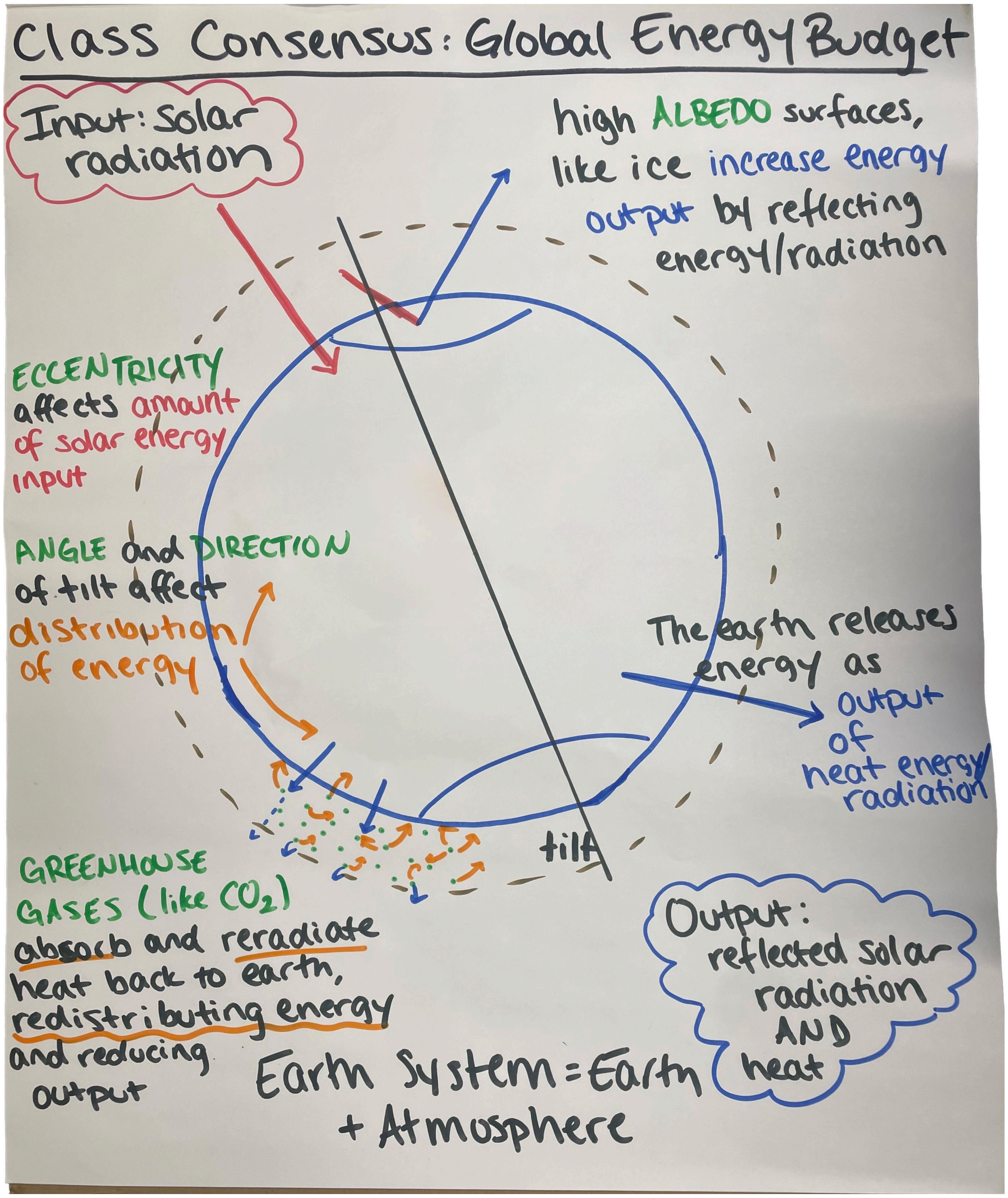
Sample Greenhouse Gases Cause and Effect Cards

Sample Greenhouse Gas Cause and Effect Cards


Effect: The cryosphere releases CO2
Cause/mechanism 1:
CO2 trapped in the cryosphere is released when the cryosphere melts
Cause/mechanism 2:
Bacteria in the cryosphere start producing CO2 and methane
Effect: the ocean releases CO2
Cause/mechanism:
When water temperatures rise, water holds less CO2 and it is released into atmosphere
Effect: Emissions of greenhouse gases increase
Cause/mechanism:
Burning fossil fuels, starting during the Industrial Revolution
Effect: Less solar radiation is reflected away from Earth's surface and therefore more becomes absorbed by Earth's surface and converted to heat that is re-released into the atmosphere
Cause/mechanism:
The albedo effect. Ice is lighter colored than water or land and reflects more light away from Earth
Effect: Atmospheric temperature rises
Cause/mechanism 1:
Greenhouse effect: greenhouse gases reradiate heat towards Earth
Cause/mechanism 2:
More solar energy is absorbed by Earth and converted to heat
Effect: Arctic ice melts
Cause/mechanism:
Increasing temperatures melt ice

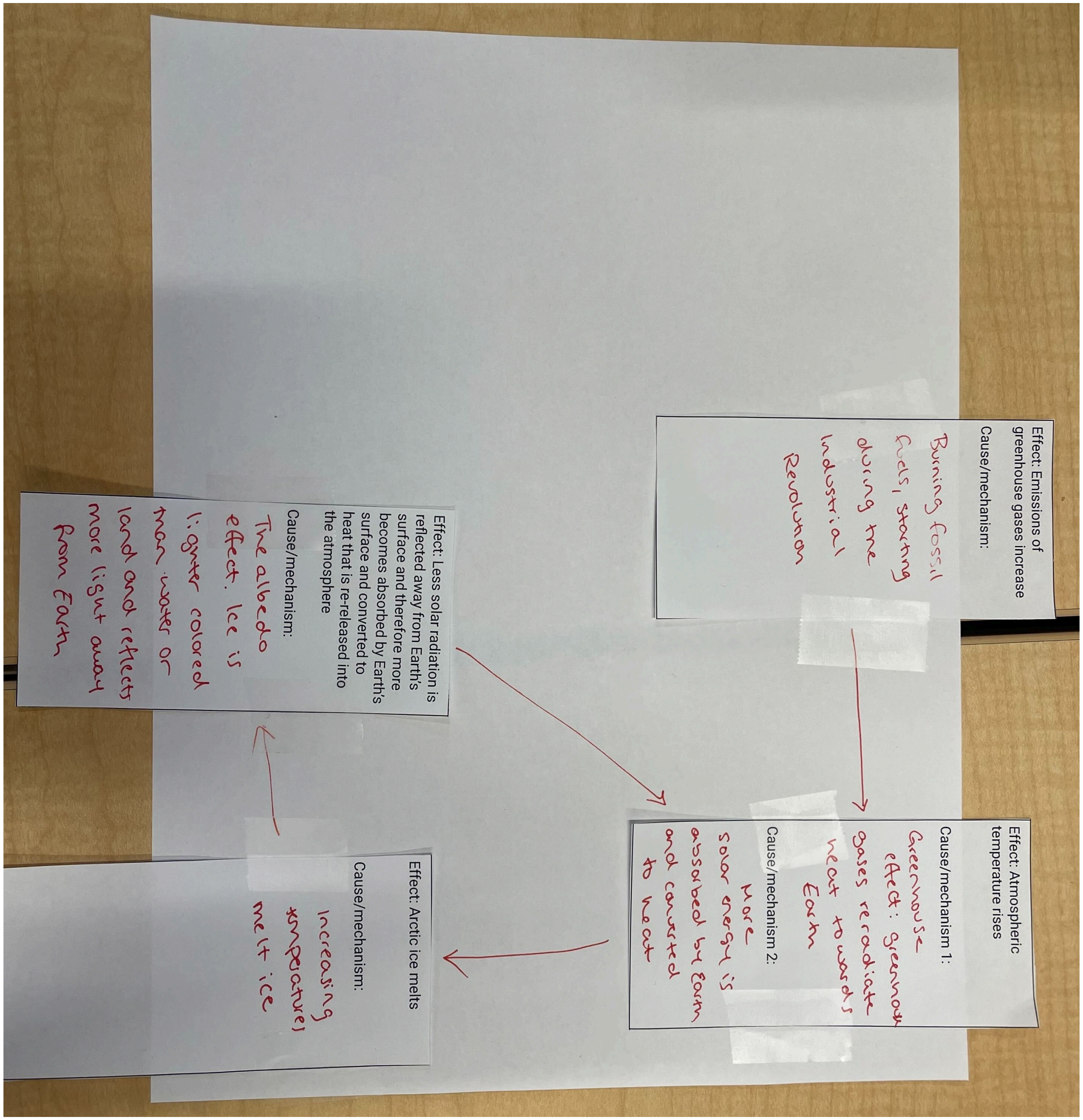

Effect: The cryosphere releases CO2
Cause/mechanism 1: CO2 trapped in the cryosphere is released when the cryosphere melts
Cause/mechanism 2: Bacteria in the cryosphere start producing CO2 and methane
Effect: the ocean releases CO2
Cause/mechanism: When water temperatures rise, water holds less CO2 and it is released into atmosphere
Effect: Emissions of greenhouse gases increase
Cause/mechanism: Burning fossil fuels, starting during the Industrial Revolution
+ Released CO2 from cryosphere and ocean
Effect: Less solar radiation is reflected away from Earth's surface and therefore more becomes absorbed by Earth's surface and converted to heat that is re-released into the atmosphere
Cause/mechanism: The albedo effect. Ice is lighter colored than water or land and reflects more light away from Earth
Effect: Atmospheric temperature rises
Cause/mechanism 1: Greenhouse effect: greenhouse gases reradiate heat towards Earth
Cause/mechanism 2: More solar energy is absorbed by Earth and converted to heat
Effect: Arctic ice melts
Cause/mechanism: increasing temperatures melt ice

Sample Class Consensus Model: Global Energy Budget after Ice Caps



Sample Ice Caps Cause and Effect Cards

Sample Ice Caps Cause and Effect Cards


Effect: Emissions of greenhouse gases increase
Cause/mechanism:
Burning fossil fuels, starting during the Industrial Revolution
Effect: Atmospheric temperature rises
Cause/mechanism 1:
Greenhouse effect: greenhouse gases reradiate heat towards Earth
Cause/mechanism 2:
More solar energy is absorbed by Earth and converted to heat
Effect: Arctic ice melts
Cause/mechanism:
Increasing temperatures melt ice
Effect: Less solar radiation is reflected away from Earth's surface and therefore more becomes absorbed by Earth's surface and converted to heat that is re-released into the atmosphere
Cause/mechanism:
The albedo effect. Ice is lighter colored than water or land and reflects more light away from Earth

Classroom Resources for Climate Feedbacks 5E

Greenhouse Gas Feedback Mechanisms
Ice Caps Cause and Effect Cards

Greenhouse Gas Feedback Mechanisms

Effect: the ocean releases CO_2 Cause/mechanism:	Effect: The cryosphere releases CO_2 Cause/mechanism 1: Cause/mechanism 2:

Ice Caps Cause and Effect Cards

Effect: Emissions of greenhouse gases increase Cause/mechanism:	Effect: Atmospheric temperature rises Cause/mechanism 1: Cause/mechanism 2:	Effect: Arctic ice melts Cause/mechanism:

Effect: Less solar radiation is reflected away from Earth's surface and therefore more becomes absorbed by Earth's surface and converted to heat that is re-released into the atmosphere Cause/mechanism:		

The Past and the Future 5E	Have humans experienced dramatic climate change in the past? How have human populations been impacted by climate change, and how can that inform how we might be impacted by it in the future?	**Performance Expectations** HS-ESS2-4, HS-ESS3-1, HS-ESS3-5	**Investigative Phenomenon** When climate change has occurred in the past, human populations have been impacted. The current climate change event is predicted to affect populations in the future as well.	**Time** 7 days

In this 5E instructional sequence, students are investigating the questions about what the impacts of climate change could be in the future by investigating how climate change has impacted populations in the past that surfaced during the Driving Question Board launch, such as why is climate change a big deal? Students use various models to analyze and interpret how rapid climate change has happened in the past as well as the way it affected people to determine what types of impacts it might have in the future. Students also use modeling to predict how warming temperatures could change other climate variables and the ways in which those could impact humans in the future.

ENGAGE	How have humans been impacted by climate change in the past?	Students **analyze textual and graphical data** about **human populations and past climate change** in order to begin understanding the relationship between **rapid changes** in temperature and societies.
EXPLORE 1	What impact does melting or freezing ice have on ocean currents?	Students **use models** of **interactions between Earth's ice sheets and oceans** in order to collect **empirical evidence for the causal relationship** between **expanding/retreating ice sheets** and **changes to ocean currents**.
EXPLAIN 1	How do changing ocean currents impact Earth's climate system?	Students **develop a model and use it to provide a mechanistic account** for how changes in an **ocean current** could have **caused** the **sudden cooling event (Younger Dryas)** as the **Earth came out of its last glacial period**
EXPLORE 2	How will temperature increases affect other climate variables?	Students **analyze past and present sea level data and computational models of climate change** to **quantify the change and rates of change of climate variables** to **predict the magnitudes of human impact on climate**.
EXPLAIN 2	How will melting ice impact populations around the world?	Students **gather evidence from texts** to **construct an explanation** about how hazards from climate change are **predicted to impact human populations.**
ELABORATE	How else will climate change impact humans, and how can we try to mitigate it?	Students **gather evidence from texts** to **construct an explanation** about how climate change is **impacting food supply chains**.
EVALUATE	How can we use what we learned to explain how climate change is likely to impact human populations?	Students **analyze data to make a valid claim** from **many sources of evidence** about the **predicted impacts on human populations resulting from human activities**.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Engage

How have humans been impacted by climate change in the past?

Students **analyze textual and graphical data** about **human populations and past climate change** in order to begin understanding the relationship between **rapid changes** in temperature and societies.

Preparation

Student Grouping	Routines	Literacy Strategies
None	❏ Domino Discover	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Climate and Human Populations	None	❏ Driving Question Board

Launch and Surfacing Student Ideas

1. Gather around the DQB and have a student remind the class what they were wondering about at the end of the last 5E sequence. Wonderings like these should surface:
   - Even though climate change is happening, and it is caused by humans, why does that matter?
2. Use students' questions and observations to transition to the guiding questions:
   - *How have humans been impacted by rapid climate change in the past?*
3. Tell students that there is a great deal of current research related to the questions they have generated. Provide students with the handout *Climate and Human Populations*.
4. Have students read the text independently, and then ask groups to discuss the prompts:
   - How have humans been impacted by climate change in the past?
   - What changes in temperature do you see on the graph?
   - What causes can you think of for the changes you see in the graph?
5. Use the **Domino Discover** group learning routine to surface important trends, inferences, and questions from groups' Summary sections.

Routine

The **Domino Discover** routine is an opportunity to surface students' thinking to the whole class and the teacher. In the Engage phase, it is often used to surface student ideas that can be used to transition the class to the investigation and to become aware of alternate or incomplete student ideas. Refer to the Earth & Space Science Course Guide for support with this routine.

Look & Listen For

Possible student ideas:

- Around 15,000 years ago, the climate is warming, maybe because of orbital factors
- Suddenly, around 13,000 years ago, temperatures drop
- Then, around 11,500 years ago, temperatures rise again
- During that time period, the Clovis population disappeared

6. Remind students that temperature rises show coming out of a glacial period, and ice should be melting. Ask them if they can predict why the temperatures might have suddenly plummeted, and then quickly risen afterwards.

7. Tell students that we need to take a closer look at exactly what was happening when ice melted in order to figure out what changed rapidly. Let students know that they will next have an opportunity to explore data related to their questions about how temperatures dropped, and how that impacted the Clovis population.

Explore 1

What impact does melting or freezing ice have on ocean currents?

Students **use models** of **interactions between Earth's ice sheets and oceans** in order to collect **empirical evidence for the causal relationship** between **expanding/retreating ice sheets** and **changes to ocean currents**.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❑ Melting Ice Investigation ❑ Making Sense of the Melting Ice Investigation	❑ Two large clear containers or tanks of water ❑ Blue and red food coloring with one additional color recommended ❑ Cold very salty water (recommended concentration of 400g/L NaCl) ❑ Cold freshwater ❑ Warm water	❑ The Blue Marble ❑ AMOC Model

Launch

1. Remind students that they are trying to figure out why the Earth experienced sudden cooling and heating as it transitioned out of the last glacial period

2. Remind students that, in the last investigation, they explained why the Arctic is heating up and ice sheets are melting at such a fast rate.

3. Provide students with Part 1 of the Melting Ice Investigation. Show students the The Blue Marble up to 1:32. Ask students what similarities they see between the time coming out of the last ice age and the climate change event happening now.
4. Point out to students that ice sheets are made of fresh water and ask them the following questions:
    - Where do you think the fresh water from ice sheets goes when they melt?
    - What impact do you think that has?

Students are likely to say it goes into the ground and ocean and that it can cause sea level to rise. Probe their ideas. The idea of affecting the salt concentration of the ocean or affecting the ocean currents may come up. Build on those ideas if they come up to probe how they think it will affect the salt concentration or how it might affect the ocean currents. If these ideas do not come up, then ask them the following:

- How will fresh water affect the salt concentration of the ocean?
- What effect does that have on ocean currents?

Look & Listen For

Possible student ideas and questions:

- I think that if ice sheets melt into the ocean around it, the salt concentration of that ocean water decreases because ice sheets are fresh water.
- In middle school we learned that differences in salt concentration and temperature are what cause ocean currents - maybe changing salt concentration due to melting or expanding ice sheets impact movement of ocean currents

5. Regardless of how they respond, build on their ideas and uncertainties and let students know that they will now have the opportunity to collect empirical evidence in order to test their ideas about how melting ice sheets affect ocean currents surrounding them. They will test their ideas by using a model that illustrates how changes in salt concentration of seawater near the ice sheets impacts ocean currents.

Investigation: How Changes in Salt Concentration Impact Ocean Currents

1. Provide each student with the *Melting Ice Investigation* handout. Let them know that they will be investigating the impact of melting Arctic ice sheets on a specific current called Atlantic Meridional Overturning Circulation (further referred to as AMOC) that descends toward the bottom of the ocean near Greenland.

2. Ask students to review their understanding of how ocean currents circulate by drawing a model or listing ideas in the "pre-lab" section of the handout. Have several students share their ideas with the class.

Look & Listen For

Possible student ideas:

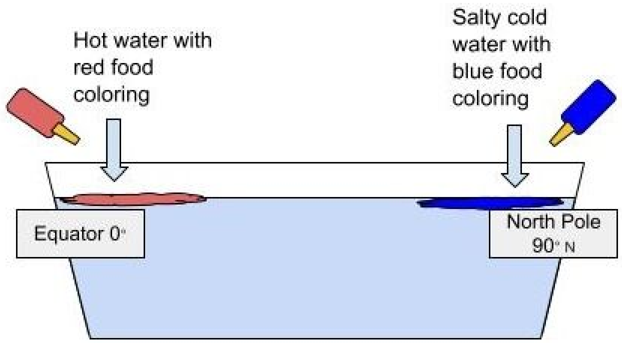
- Cold water falls, and warm water rises
- Saltier water is denser than less salty water
- Warm water comes from equatorial regions, and cold water comes from the poles

3. If students don't surface the key ideas, show the video AMOC Model .

4. Leverage student ideas to decide how to construct a model of current circulation and ask students to record their plans in the box called "Plan for Setting up the Global Ocean Circulation Model (before a glacier melts)"

Note: students will be constructing the Global Ocean Circulation Model later in the activity, after they have determined how to construct both the "before a glacier melts" and "after a glacier melts" versions of the model.

Their plans should look like this



5. Remind students that glaciers are made of freshwater. Ask them to brainstorm and write down their ideas for how they can use the global current circulation model to test their ideas and questions about how changes in the salt concentration of seawater near ice sheets can impact ocean currents.
6. Initiate a class discussion about how the model would be different if it showed glacial meltwater entering the current. Listen for students to say that the salt concentration of the water will be less because of the freshwater melt, so we should make the water less salty at the "north pole."

Look & Listen For

Possible student ideas:

- We can alter the salt concentration of water at the poles in our model to represent changes in salt concentration of ocean water around ice sheets. We can choose a level of salt concentration as our control and experiment with higher salt concentration of water.
- We can observe how these changes in salt concentration impact the ocean current in our models.
- We can see if there is a real world model for this in the ocean and analyze data to see if our models explain what is happening today.

7. Ask students to use their knowledge of density and currents to predict how the global current circulation model will change when the salinity of the cold water decreases. Have students record their predictions in the "Make a prediction" section of the handout.

Conferring Prompts

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

- How will an influx of freshwater affect the salinity of the ocean at the north pole?
- How would you model that change?
- How would a change in salinity affect the current compared to the control global current circulation model already seen?

8. Have students create the global ocean current circulation models with and without glacial melt (or construct the models as a demo) based on the class discussion.

To do so, they will designate one tank of water as the “before glacial melt” model and one tank as the “after glacial melt” model.

Make sure students have four containers of water to add to the tanks: two with hot water dyed red; one with cold, very salty water dyed blue; and one with cold, diluted salt water, dyed blue or another color.

In the “before glacial melt” tank, they will pour one cup of their hot, red-colored water into one side and their cup of cold, very salty water into the other. In the “after glacial melt” tank, they will pour their second cup of hot water into one side and their cup of cold, diluted salt water into the other.

They will record their observations in the section titled “observations of changes in ocean currents.” Students should see that the less salty water falls more slowly than the very salty water did in the original model, and that the circulation of the current has slowed.

Implementation tip: a dilution ratio of 1:1 saltwater to freshwater will create a visible difference in the speed that the cold water falls, 1:2 or 1:3 will result in a bigger visual difference.

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

Conferring Prompts

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

- What do you notice about the ocean current generated by your control model?
- How does the current generated by your model change when you decrease the salt concentration of water at the poles?
- How does the current generated by your model change when you increase the salt concentration of water at the poles?
- How do you think the current would be impacted if we continued decreasing the salt concentration at the pole?

Investigation: Whole-Class Investigation Summary

1. Ask students to work independently to complete the handout *Making Sense of the Melting Ice Investigation*. Ask groups to come up with one important idea or question that arose from their discussion to share with the whole class.

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

Look & Listen For

Possible student ideas and questions:

- When we decreased the amount of salt at the poles, the current formed but it took longer to form and it moved more slowly when compared to the control.
- When we increased the amount of salt at the poles, the current formed more quickly and it moved faster when compared to the control.
- I think this means this could have happened in the past when ice sheets were retreating and expanding
- I think currents would keep slowing down (or maybe even stop) if glacial melt continued to dilute the salt concentration of the water at the poles
- What implications did this have for climate in the past?
- What does this tell us about our climate in the future?

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

Access for Multilingual Learners

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

Explain 1

How do changing ocean currents impact Earth's climate system?

Students **develop a model and use it to provide a mechanistic account** for how changes in an **ocean current** could have **caused** the **sudden cooling event (Younger Dryas)** as the **Earth came out of its last glacial period**

Preparation

Student Grouping	Routines	Literacy Strategies
❏ Table Groups	❏ Class Consensus Discussion	❏ Sequence Chart

Materials

Handouts	Lab Supplies	Other Resources
❏ Melting Ice and Currents ❏ Summary Task	None	❏ *The End of the Clovis Population Cards* ❏ From the previous 5E: Class Consensus Model: Global Energy Budget ❏ The Catastrophic Flood that Triggered an Ice Age

Launch

1. Display the temperature graphs showing the Earth transitioning out of the last glacial period from the Engage phase. Highlight the sudden cooling that happened during that time. Tell students that they will now have an opportunity to revisit their questions and apply their ideas related to sensemaking around whether changing ocean currents occurred while the Earth was transitioning out of the last glacial period and whether they can explain the sudden cooling that happened during that time.

2. Let students know that they will now have an opportunity to see if they can use scientific ideas to develop a model that illustrates *the mechanism* for how changes in ocean currents occur due to changes in ice and how those changes could have caused sudden cooling in the northern hemisphere.

Developing a Model for How Changes in Ocean Currents Occur and Impact Climate

1. Ask students to work in small table groups and provide students with the handout, *Melting Ice and Currents*.

2. Confer with students as they develop their models for part 1.

Conferring Prompts

Confer with students while they develop their models. Suggested conferring questions:

- What happened to the salt concentration? What caused that?
    - How does your model show that?
- How does that affect the ocean current? What evidence do you have for that?
    - How does your model show that?

3. After students have completed their models for part 1, tell students that in order to deepen their understanding of how changing ocean currents can impact global temperatures, they will have a chance to read more about the role of water in transferring heat. Knowing about heat transfer will help us understand the warming and cooling periods we see in the data. Have students proceed to Part 2 to analyze the Surface Ocean Currents Model and read the text within the handout, *Ocean Heat Storage and Transfer*, using the following annotation strategy:
    - Checkmark ideas that connect to or confirm your current ideas
    - Circle ideas that help answer a question you had
    - Write a question mark next to ideas that you are unclear of and would like to discuss with classmates.

4. Ask students to take turns sharing their annotations with a partner and decide which annotated ideas from the text they would like to share or discuss with the class. Then lead a class discussion around these ideas.

Look & Listen For

Possible student ideas and questions:

- AMOC transports water from near the equator toward the Arctic.
- The water becomes colder and sinks.
- Water is high density and has a high heat capacity.
- These two properties allow water to store a lot of energy compared to other substances like air.
- The transfer of heat can occur in three ways: conduction, convection, and radiation.
- Heat transfer occurs between states of matter whenever a temperature difference exists and heat transfer occurs only in the direction of decreasing temperature, meaning from a hot object to a cold object.
- The way heat is transferred between water and air is through both conduction and convection, but mostly convection because water is a poor conductor of heat, but its most energetic molecules evaporate into the air and take their kinetic energy with them, transferring heat energy when it collides with less energetic air molecules as it condenses.

Integrating Three Dimensions

The models students develop during this Explain 1 phase are an opportunity to integrate the three dimensions. Students will develop models that account for the conservation of carbon within the Earth system, then use all they have figured out in this 5E so far to develop a model that explains how a change in ocean currents could have caused the sudden warming at the end of the Younger Dryas.

5. Ask students to apply what they have learned to complete part 2 and develop a model for how ocean currents impact climate.

6. Once students have understood how ocean currents transport energy and influence climate, have students apply that knowledge to the End of the Clovis Population. Provide students with *The End of the Clovis Population Cards* and have students complete Part 3 of the handout.

Class Consensus Discussion

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

We may have a lot of different ideas circulating in the room right now, and it is really important for us to get to some agreement about how changes in ocean currents impacted human populations, so we have a shared understanding to build on as we move ahead. In order to do this, we are going to have 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 model and discuss what we can agree on as a class.*

2. You may decide to walk students through the entire poster of the Class Consensus Steps or take them through the steps as you facilitate it.

3. Post a piece of chart paper or two in front of the classroom and title it "Class Consensus: Ocean Currents and Climate."

4. 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 Earth's varying position with respect to the Sun impacts the radiation reaching Earth and glacial-interglacial cycles. 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.

5. 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.

6. Proceed through the Consensus Discussion Steps.

Routine

Class Consensus Discussions are so important for the Explain phase across this unit. This routine is a way to ensure that the accurate scientific ideas students are figuring out are made public and visible for all students to access. It requires skillful teacher facilitation, as it is important to not tell students what they need to know, instead supporting students as a class in using the information they have from investigations, their models and texts in order to figure out and state those important ideas. Please read the Unit 1 Teacher Guide for detailed steps of this routine.

Class Consensus Discussion Steps

1. We listen to 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.
7. We agree or disagree (and tell why) with the ideas or offer revision ideas.

7. Before table groups confer, prompt them to consider the strength of their explanations. Some prompts you might provide are:
    - What evidence do you have?
    - What is the mechanism for what you are claiming? What are the science ideas involved?
    - How confident do you feel about your claims? Why?

8. Resume the whole class discussion and, as the class agrees on important ideas or clear ways to represent their ideas, add them to the Class Consensus List.

9. After all student ideas are captured on the class consensus list, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). Having questions at this point is fine and you should expect some to be there.

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

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #2 - Cause and Effect** explicit for students by elevating and probing for ideas related to the idea of **Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects**, an important element of cause and effect at the high school level.

Take Time for These Key Points

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

- Ocean currents transport radiation from the Sun that was absorbed in the ocean to different places around the globe.
- The AMOC ocean current carries warm water north where it cools and becomes more salty.
- Colder and saltier water is more dense than warmer and less salty water.
- Melting glaciers released fresh water into the ocean where AMOC sinks
- Because the salt concentration of ocean water affects how dense it is and how fast it sinks, the AMOC current clouds have slowed because of melting glaciers, so less heat would have been transported to the northern latitudes, causing decreases in air temperature.
- However, as warm air built up in the southern hemisphere and began to move North, temperatures rose very quickly
- The rebounding of temperatures from warm to cold to warm created floods and impacted wildlife, resulting in the loss of the Clovis population

11. When the class feels satisfied with their model, add the key summary information to the *Class Consensus Model: Global Energy Budget*, with an emphasis that currents change the distribution of energy on Earth.

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

13. The results of this task can be used to make determinations about which students need more time to circle back to the ideas in this text, in the coming parts of the 5E lesson.

Implementation Tip

Implementation

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

Explore 2

How will temperature increases affect other climate variables?

Students **analyze past and present sea level data and computational models of climate change** to **quantify the change and rates of change of climate variables** to **predict the magnitudes of human impact on climate**.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❑ Forecasting the Future Investigation Part 1 ❑ Forecasting the Future Investigation Part 2 ❑ Making Sense of the Forecasting the Future Investigation	None	❑ Sea Level Change Data Spreadsheet ❑ What The US Would Look Like If All The Earth's Ice Melted ❑ IPCC WGI Interactive Atlas: Regional information (Advanced)

Launch

1. Remind students that we are still trying to understand why climate change is a big deal. We know now how rapid climate change may have impacted populations in the past, but we haven't yet determined how it could affect people today and in the future.

2. Ask students what they have already heard about how climate change could impact people. Have students share their ideas. Help students build on what they learned in the last investigation about warming leading to ice sheets melting and flooding increasing.

3. Regardless of how they respond, build on their ideas and uncertainties and let students know that they will now have the opportunity to investigate some anticipated climate related changes using data showing how some variables on Earth have changed since warming began, and use that information to predict what will happen in the future.

Investigation: Forecasting the Future

1. Provide each student with the *Forecasting the Future Investigation Part 1* handout. Let them know that they will be investigating the impact of rising sea levels.

2. Have students work in pairs to open the Sea Level Change Data Spreadsheet and analyze the data by constructing line graphs showing the sea level change over time.

3. Support students as they conduct more in depth data analysis, including calculating annual sea level change and the rate of sea level change over 32 years. Students will use that rate of change to anticipate how much sea levels will rise in the next 50 and 100 years.

4. When students are done with this part, pause the class and ask students to share:
    - Their calculated average seasonal variation
    - Their calculated average monthly rate of change of seasonal variation
    - Their calculated rate of sea level change over 32 years
    - Their predicted amounts of sea level over 50 and 100 years

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Look & Listen For

Possible student ideas:
- The average seasonal variation is 14.265625mm
- The average rate of change of seasonal variation is 2mm/month during melt times
- The rate of annual change is 3.0125mm/year over the past 32 years
- In 50 years, sea levels would rise 150.625 mm (about 6 inches)
- In 100 years, sea levels would rise 301.25 mm (about 12 inches)

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5. Tell students that global averages are important, but that sea level rise is not expected to be evenly distributed around the planet. Some areas will see more sea level rise than others. Additionally, different conditions on coasts mean that people will be affected differently around the world. Tell students that they will now have the opportunity to explore sea level rise along with other climate variables to see how they will change either where they live or in another area that interests them.

Implementation Tip

If time or access to computers is a challenge, this next part can be done as a classroom demo by having the teacher project the IPCC interactive atlas and having the class manipulate variables together.

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6. Provide students with the *Forecasting the Future Investigation Part 2* handout. Help students navigate the IPCC WGI Interactive Atlas to observe sea level rise under different warming scenarios. Explain to them that these warming scenarios are based on how much fossil fuel use is expected to happen in the future, and that scientists have used computational models to project what will happen to different variables if those amounts of fossil fuels are burned.

    - Under warming scenario SSP1-2.6, we are expected to see a temperature rise of 1.8 degrees C by 2080
    - Under warming scenario SSP2-4.5, we are expected to see a temperature rise of 2.7 degrees C by 2080
    - Under warming scenario SSP3-7.0, we are expected to see a temperature rise of 3.6 degrees C by 2080

- Under warming scenario SSP5-8.5, we are expected to see a temperature rise of 4.4 degrees C by 2080

7. Students should choose to observe an area related to where they live, or another one that has importance to them.

8. Support students as they explore different variables under all warming scenarios. Confer with students as they work.

Conferring Prompts

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

- How are you choosing which variables to explore?
- How do the variables change under different warming scenarios?
- How do you think those variables might be related?

Differentiation Point

Students may need support in figuring out how to read the data from the interactive. Students should be using the "time series" data to observe what is happening in the year 2080 for their region of interest. They do not need to record quantitative data about these changes, but should focus on increasing or decreasing trends, and how the rates of change vary as the warming scenarios change.

9. Ask students if they have any idea how their communities or the communities located in the areas they investigated would be impacted by the changes they saw predicted by the model.

10. Tell students that they will now take a closer look at sea level rise, since we know that changing sea levels can have a big impact on populations. Tell them that they will use two more tools: one to help them determine exactly how much sea levels are expected to rise by 2080, and another to help them visualize those changes.

11. Have students open the Sea Level Projection Tool. Students should choose a location on the map, select year "2080" from the drop down tab, and record the projected temperature rise under each condition.

12. Finally, have students open the Sea Level Rise Viewer. They should select the same location as they observed using the Sea Level Projection Tool. Make sure students switch the unit to "meters" and then use the sea level rise viewer tool to observe what neighborhoods will look like if the water rises to the extent predicted in the Sea Level Projection Tool from the previous step.

Whole-Class Investigation Summary

1. Ask students to work independently to complete the *Making Sense of the Forecasting the Future Investigation* handout. Table groups should discuss their responses to the analysis questions. Ask

groups to come up with one important idea or question that arose from their discussion to share with the whole class.

2. Use the group learning routine **Domino Discover** to surface important trends, inferences, and questions from each group's Investigation Summary.

Look & Listen For

Possible student ideas and questions:

- As temperatures continue to rise, precipitation patterns, sea ice, and sea levels are all expected to change
- Making predictions in models depends on predicting how the input variables, like greenhouse gas emissions, will change in the future
- Whether or not these changes can be reversed depends on the extent of the changes and how quickly they happen
- If temperatures continue to rise and ice continues to melt, floods could increase, and the AMOC current could potentially slow down or even stop

3. Plan forward based on the various understandings that students or student groups have articulated. It is appropriate to go onto the next phase once students have had a chance to make sense of the data, and have had the opportunity to clarify what they have figured out about the investigative phenomenon under study in this learning sequence

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

5. Close the discussion by showing students the video What The US Would Look Like If All The Earth's Ice Melted . Ask students to share their reactions to the video.

Explain 2

How will melting ice impact populations around the world?

Students **gather evidence from texts** to **construct an explanation** about how hazards from climate change are **predicted to impact human populations.**

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Table Groups	❑ Read Generate Sort Solve ❑ Class Consensus Discussion	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Impacts of Melting Ice ❑ Text 1 - Glacial Lakes ❑ Text 2 - Mountains ❑ Text 3 - The Poles ❑ Summary Task	None	❑ Chart Paper ❑ Class Consensus Discussion Steps

Launch

1. Ask students to brainstorm how melting ice might affect populations, besides rising sea levels. Ask them if they have heard about any other impacts or could imagine how melting ice might be a problem in other ways.

2. Tell students that they will now read about real ways in which melting ice is affecting communities.

Explaining the Impacts of Melting Ice

1. Organize students into table groups of 3-4 students. Provide students with the handout *Impacts of Melting Ice*. Within each group, jigsaw texts 1-3. Have students individually read their texts using this annotation strategy:
    - Checkmark ideas that connect to or confirm your current ideas
    - Circle ideas that help answer a question you had
    - Write a question mark next to ideas that you are unclear of and would like to discuss with classmates.

2. When students are done reading, have them generate ideas around the prompt "how will climate change impact populations?" Facilitate the group learning routine Read Generate Sort Solve to help students discuss their ideas and then individually write their responses.

3. After students have finished, provide them with chart paper to record a joint response to share during the class consensus discussion.

Integrating Three Dimensions

In this unit students are developing proficiency with the **CCC#2 Cause and Effect**, differentiating between cause and correlation. Remind students about the meaning of both correlational and causal relationships.

Class Consensus Discussion

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

*We are going to use a **Class Consensus Discussion**, just like we did in the last 5E, to learn about all the thinking in the room and come to some decisions about why climate change is such a big deal based on how it will impact people.*

2. You may decide to walk students through the entire poster of the Class Consensus Discussion Steps or take them through the steps as you facilitate it.

3. Post a piece or two of chart paper in front of the classroom and title it "Class Consensus: How Changes in Ocean Currents Impacts Climate." You will be recording student ideas on this paper as they surface during presentations.
4. 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 Earth's varying position with respect to the Sun impacts the radiation reaching Earth and glacial-interglacial cycles. 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.

5. Ask the first student or group to share their explanations and models. Ask student groups to use the models on their handouts as they explain the causal mechanisms. You can do this by:
    - projecting using a document camera, OR
    - copying the written explanation to be shared and passing them out to the class, OR
    - taking a picture of each explanation and projecting them as slides.

6. Proceed through the Consensus Discussion Steps.

Routine

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

7. Before table groups confer, prompt them to consider the role of systems and systems models in figuring out which claim is best supported. Some prompts you might provide are:
    - What evidence do you have for your model?
    - What is the mechanism for what you are claiming? What are the science ideas involved?
    - How confident do you feel about your claims? Why?

8. Resume the whole class discussion and as the class agrees on important ideas or clear ways to represent their ideas, add them to the Class Consensus Chart.

9. After all student ideas are captured on the class model, ask the class if they agree, have different ideas, or if they disagree. If students disagree about or are uncertain of ideas, label them with a question mark (?). During the whole class discussion, there will be opportunities to identify important terms and concepts that emerge. Sometimes, important points may get buried in student talk.

Class Consensus Discussion Steps

1. We listen to 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.
7. We agree or disagree (and tell why) with the ideas or offer revision ideas.

Take Time for These Key Points

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

- Floods are driving communities to relocate, not just in coastal regions
- Floods create landslides in hilly/mountainous regions, which also cause damage, kill people, and cause populations to move
- Changes in mountain conditions affect agriculture and access to food
- Higher waves cause more coastal damage, shrinking coastlines from both erosion and rising water lines
- Changes in water conditions impact sea food stocks
- Globally, people are seeing many impacts through different facets of life

11. Return to student questions that bring up lingering issues not yet resolved, such as:
    - Are there other ways that climate change impacts people?

Integrating Three Dimensions

The depth of this discussion will really depend on what you've observed in the room and how you respond. Be sure to make **CCC #2 - Cause and Effect** explicit for students by elevating and probing for ideas related to the concept that empirical evidence is required to differentiate between causation and correlation, an important element of cause and effect at the high school level. The prompts about patterns in the Class Consensus Discussion are in support of students' consideration of **CCC #2 - Cause and Effect**.

12. If students are asking about solutions or ways to reverse climate change, tell students that they will have an opportunity to learn more about sustainable solutions in Unit 6.

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

14. The results of this task can be used to make determinations about which students need more time to circle back to the ideas in this text, in the coming parts of the 5E lesson.

Implementation Tip

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

Elaborate

How else will climate change impact humans, and how can we try to mitigate it?

Students **gather evidence from texts** to **construct an explanation** about how climate change is **impacting food supply chains**.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ Triads	❑ Think-Talk-Open Exchange	None

Materials

Handouts	Lab Supplies	Other Resources
❑ Managing Other Climate Change Disruptions	None	❑ These crops are suffering most from climate change | World Economic Forum ❑ How Climate Extremes are Causing World Hunger

Launch

1. Revisit student ideas and questions regarding the other types of impacts that climate change will have on populations
2. Tell students that they will watch two videos to help them understand the wide ranging effects of climate change

Constructing an Explanation

1. Organize students into triads and provide students with the handout *Managing Other Climate Change Disruptions*
2. **Either as a class or in groups, have students watch the videos: These crops are suffering most from climate change | World Economic Forum and How Climate Extremes are Causing World Hunger .**
3. **Facilitate the group learning routine think-talk-open exchange to support students in generating ideas around the prompt How is climate change affecting populations, and what actions could be taken to prevent increasing harm?**

4. **Have students write their final responses individually.**

Evaluate

How can we use what we learned to explain how climate change is likely to impact human populations?

Students **analyze data to make a valid claim** from **many sources of evidence** about the **predicted impacts on human populations resulting from human activities**.

Preparation

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

Materials

Handouts	Lab Supplies	Other Resources
❏ Revisiting the Performance Task: Greenhouse Gases 5E ❏ Human Displacement and Disaster Data	None	❏ Chart paper ❏ Sticky Notes

Revisit the Performance Task

1. Provide students with the handout *Unknown material with identifier: ess.u4.l4.evaluate.h*
2. Students can work individually or in groups to analyze the data and determine how human populations have been impacted on large scales from climate related hazards and disasters
3. After students have engaged in sense-making around that data, have them turn to their performance task organizer.
4. Confer with students while they are working on their performance task organizer.

Conferring Prompts

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

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

Document Class Thinking

1. Prompt students to discuss how humans are being impacted by climate related disasters. Students can use the notes in their performance task organizers in these discussions.
2. Conduct a **Domino Discover** to hear from each group, and tally the responses on chart paper. It is not necessary to discuss all the positions.

Performance Expectations

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

In NYS the clarification statement has been edited as follows: Examples of the causes of climate change could include those that differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation, solar output; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition and plate tectonic.

HS-ESS3-1 **Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.**
Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.
Assessment Boundary: None

In NYS, the clarification statement has been edited as follows: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards could include those from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as blizzards, hurricanes, tornados, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations could include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.

HS-ESS3-5 **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.**
Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).
Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.

In NYS the clarification statement has been edited as follows: Examples of evidence could include both data and climate model outputs that are used to describe climate changes...

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) • Use a model to provide mechanistic accounts of phenomena. SEP2(5) Analyzing and Interpreting Data • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. SEP4(1) • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. SEP4(2)	ESS2.A Earth Materials and Systems • The geologic record shows that changes to global and regional climate can be caused by interactions among changes in the Sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. ESS2.A(3) ESS2.D Weather and Climate • The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. ESS2.D(1) ESS3.A Natural Resources • Resource availability has guided the development of human society. ESS3.A(1) ESS3.D Global Climate Change • Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. ESS3.D(1)	Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. CCC2(1) Energy and Matter • The total amount of energy and matter in closed systems is conserved. CCC5(1) Stability and Change • Feedback (negative or positive) can stabilize or destabilize a system. CCC7(3)

Assessment Matrix

	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Developing and Using Models		*Melting Ice and Currents Summary Task* *Melting Ice Investigation* *Making Sense of the Melting Ice Investigation*		*Managing Other Climate Change Disruptions*	
Analyzing and Interpreting Data			*Impacts of Melting Ice Text 1 - Glacial Lakes*		*Revisiting the Performance Task: Greenhouse Gases 5E*
ESS2.A Earth Materials and Systems		*Melting Ice Investigation* *Making Sense of the Melting Ice Investigation*		*Managing Other Climate Change Disruptions*	*Revisiting the Performance Task: Greenhouse Gases 5E*
ESS2.D Weather and Climate	*Climate and Human Populations*	*Melting Ice Investigation* *Making Sense of the Melting Ice Investigation* *Melting Ice and Currents Summary Task*		*Managing Other Climate Change Disruptions*	*Revisiting the Performance Task: Greenhouse Gases 5E*
ESS3.A Natural Resources			*Impacts of Melting Ice Text 1 - Glacial Lakes*		
ESS3.D Global Climate Change				*Managing Other Climate Change Disruptions*	
Cause and Effect			*Impacts of Melting Ice Text 1 - Glacial Lakes*	*Managing Other Climate Change Disruptions*	*Revisiting the Performance Task: Greenhouse Gases 5E*
Energy and Matter	*Climate and Human Populations*	*Melting Ice Investigation* *Making Sense of the Melting Ice Investigation* *Melting Ice and Currents Summary Task*	*Impacts of Melting Ice Text 1 - Glacial Lakes*		*Revisiting the Performance Task: Greenhouse Gases 5E*
Stability and Change		*Melting Ice and Currents Summary Task*			*Revisiting the Performance Task: Greenhouse Gases 5E*

Common Core State Standards Connections

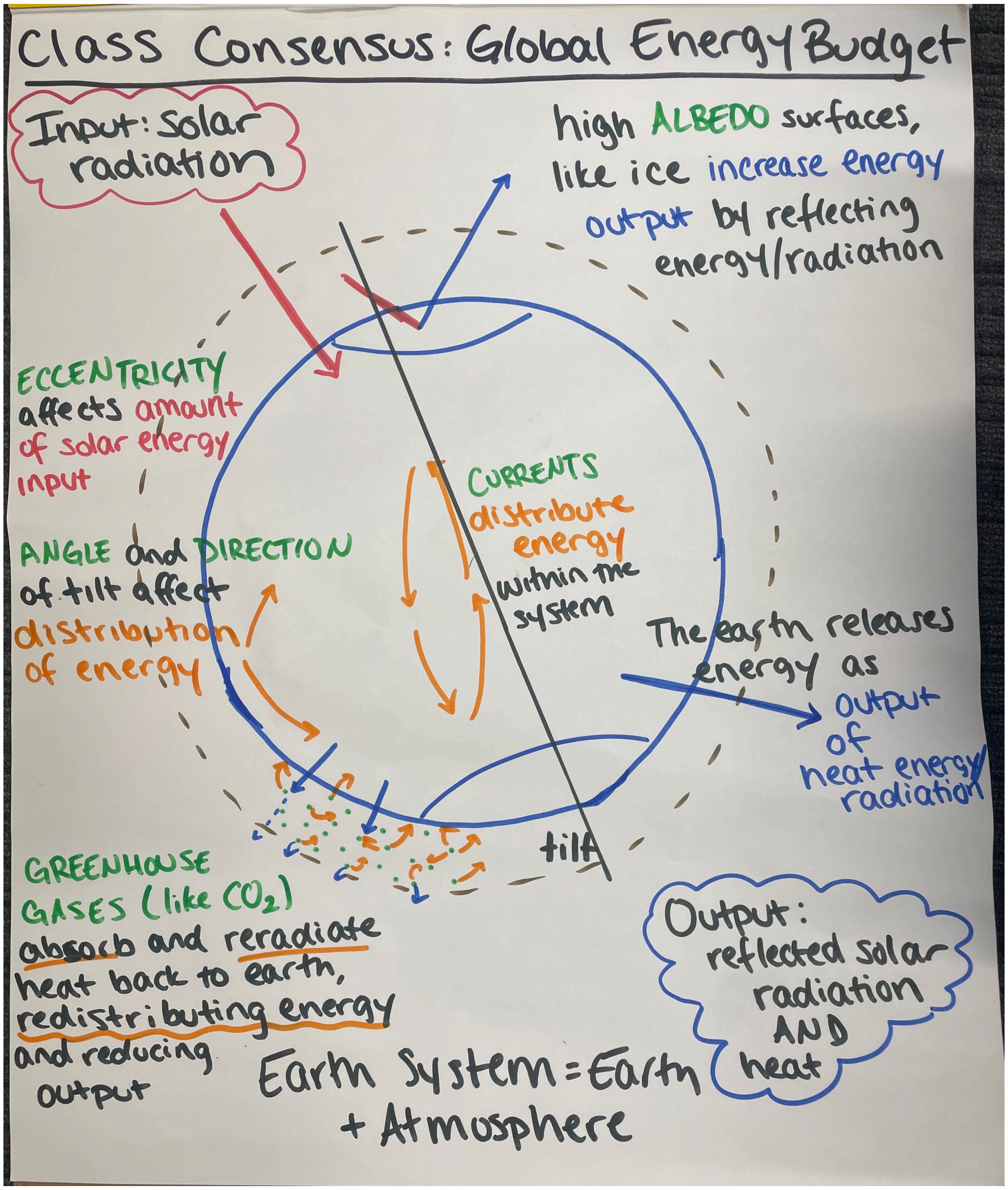
	Engage	Explore/Explain 1	Explore/Explain 2	Elaborate	Evaluate
Mathematics		MP2 MP3 MP4 MP6	MP2 MP3 MP4 MP6		
ELA/Literacy		WHST.9-10.9	WHST.9-10.9	WHST.9-10.1 WHST.9-10.5 SL.9-10.4	WHST.9-10.1 WHST.9-10.9

Classroom Resources for The Past and the Future 5E

Sample Class Energy Budget Model Complete
The End of the Clovis Population Cards

Sample Class Energy Budget Model Complete

Sample Class Consensus Model: Global Energy Budget Complete



The End of the Clovis Population Cards

Cut out these cards

Orbital factors shifted	Increased solar radiation reaching the northern hemisphere in the summer	Temperatures increased
Positive feedback loops in the form of greenhouse gases and decreasing albedo amplified temperature increase	Ice caps melted	The AMOC slowed down or even stopped
Energy circulation of the ocean stopped	The northern hemisphere received less heat from the equator	The northern hemisphere cooled quickly
Warm air built up in the southern hemisphere	Warm air eventually moved from the southern hemisphere to the northern hemisphere	Temperatures increased dramatically

Flooding increased on coastal regions as sea level rose from melted glaciers
Food supply was impacted by dramatic climatic warming and cooling in quick succession
The clovis people as a population were not able to survive

# Unit Closing	How do natural factors contribute to changes in Earth's temperature? What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	**Performance Expectations** HS-ESS3-1, HS-ESS3-5	**Anchor Phenomenon**	**Time** 1-3 days

Based on the investigations and learning throughout the unit, students generate a final explanation detailing how humans are causing climate change and why it matters to their community.

ANCHOR PHENOMENON	What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	Based on the investigations and learning throughout the unit, students review their ideas for why scientists are sure that humans are causing climate change and why it matters.
DRIVING QUESTION BOARD	What questions have been answered? What have we not answered yet?	Based on the investigations and learning throughout the unit, students return to the Driving Question Board to reflect on questions generated throughout the unit.
PERFORMANCE TASK	What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?	Based on the investigations and learning throughout the unit, students generate a final explanation of why scientists are certain that humans are causing climate change and why it matters.

Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts

Anchor Phenomenon

What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?

Based on the investigations and learning throughout the unit, students review their ideas for why scientists are sure that humans are causing climate change and why it matters.

Preparation

Student Grouping	Routines	Literacy Strategies
❑ None	None	None

Materials

Handouts	Lab Supplies	Other Resources
❑ None	None	

Generating Ideas about Anchor Phenomenon

1. Students return to the anchor phenomenon and review their ideas for why scientists are sure that humans are causing climate change and why it is a problem.

Driving Question Board

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

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

Preparation

Student Grouping	Routines	Literacy Strategies
None	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. Questions about reducing the impact of climate change or reversing the trend will surface again in Unit 6, Solutions for a Sustainable Future.

Performance Task

What are 99.9% of climate scientists seeing in historical climate data that makes them so sure humans are the cause of climate change today, and why does it matter?

Based on the investigations and learning throughout the unit, students generate a final explanation of why scientists are certain that humans are causing climate change and why it matters.

Preparation

Student Grouping	Routines	Literacy Strategies
❏ None	None	None

Materials

Handouts	Lab Supplies	Other Resources
❏ Final Performance Task	None	

Unit Closing Task

1. Remind students of our overarching goal to disprove any skeptic who claimed that humans are not the cause of current climate change and to demonstrate why it matters.
2. Provide students with the Unit Closing Task.
3. Students should use evidence from all of the investigations to explain how we know that humans are causing climate change, how that impacts other climate variables, and how that is likely to affect members of their community. Students can use different formats for this explanation.

Standards in Unit Closing

Performance Expectations

HS-ESS3-1 **Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.**
Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.
Assessment Boundary: None

In NYS, the clarification statement has been edited as follows: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards could include those from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as blizzards, hurricanes, tornados, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations could include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.

HS-ESS3-5 **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.**
Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).
Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.

In NYS the clarification statement has been edited as follows: Examples of evidence could include both data and climate model outputs that are used to describe climate changes...

Aspects of Three-Dimensional Learning

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. SEP4(2) Constructing Explanations and Designing Solutions • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. SEP6(2)	ESS3.B Natural Hazards • Natural hazards and other geologic events have shaped the course of human history; they have significantly altered the sizes of human populations and have driven human migrations. ESS3.B(1) ESS3.D Global Climate Change • Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. ESS3.D(1)	Patterns • Empirical evidence is needed to identify patterns. CCC1(5) Cause and Effect • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. CCC2(1)

Assessment Matrix

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Analyzing and Interpreting Data			*Final Performance Task*	
Constructing Explanations and Designing Solutions			*Final Performance Task*	
ESS3.B Natural Hazards	Generating Ideas		*Final Performance Task*	
ESS3.D Global Climate Change			*Final Performance Task*	
Patterns			*Final Performance Task*	
Cause and Effect	Generating Ideas			

Common Core State Standards Connections

	Anchor Phenomenon	Driving Question Board	Performance Task	Unit Reflection
Mathematics	MP.2 MP.4			
ELA/Literacy	RST.9-10.1 RST.9-10.7 WHST.9-10.2 WHST.9-10.1 WHST.9-10.9 SL.9-10.4			